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LRAPP VERTICAL ARRAY. PHASE II

C. H. Jones

Westinghouse Electric Corporation

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A vertical array of six hydrophones on a 13,050 ft. cable was built for measuring noise in the ocean over the frequency band from 10 Hz to 300 Hz. The hydrophones have a high sensitivity to acoustic signals. They have a low self noise and a low sensitivity to acceleration. The small size and ruggedness of the connector hydrophone makes it practical to wind the entire array onto a drum so that it can be deployed and retrieved with a minimum amount of handling. Special watertight connectors were designed that fit inside a pair of split cylinders which mechanically couple each hydrophone to the cable

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20. (continued) sections. This permits the replacement of a hydrophone simply by uncoupling the split couplers, unplugging the old hydrophone and plugging in the new hydrophone.

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1. INTRODUCTION

A vertical transducer array of six WX-VERAY-1 hydrophones was designed to monitor ambient noise from 10 Hz to 300 Hz, see Fig. 1. Signals from the six hydrophones are fed to an electronic package at the bottom of the array where they are recorded on magnetic tape. Westinghouse Electric Corporation had responsibility for supplying the 13,050 ft. of cable from the clevis below the top float down to the clevis at the bottom end of the cable. Westinghouse also designed and built a module containing a regulated power converter and a set of six termination amplifiers. The module also contains circuitry to disconnect the battery power during recovery of the array when the connector on the breakaway cable is exposed to sea water.

A spare set of cables, an extra termination module and two spare hydrophones (Fig. 2) were also provided.

In order to check the operation of the hydrophones on board ship, an acoustic source was provided which was used in air to make a quick check of the hydrophones after they were connected to the cables.

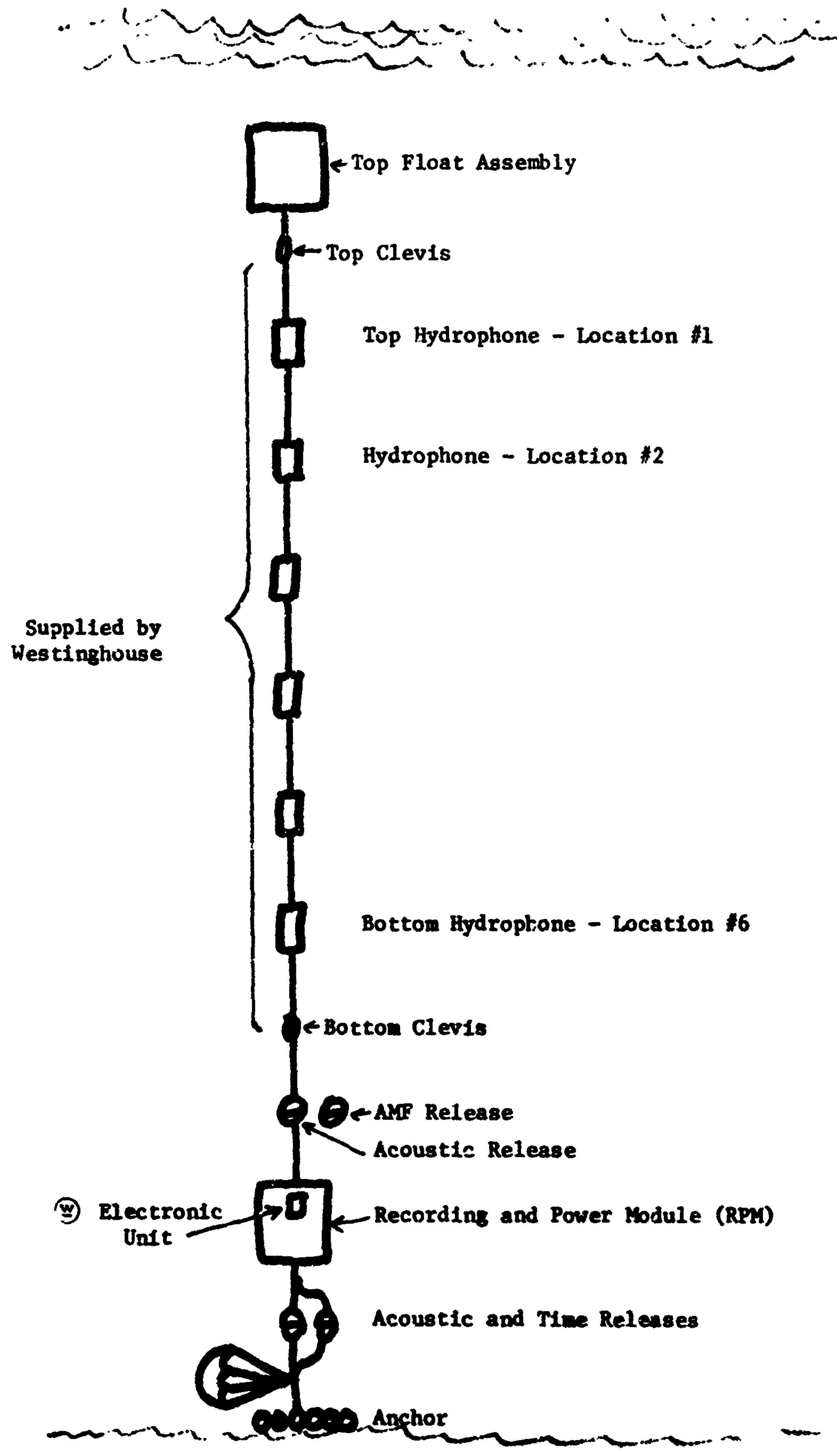


Fig. 1 - Vertical Transducer Array

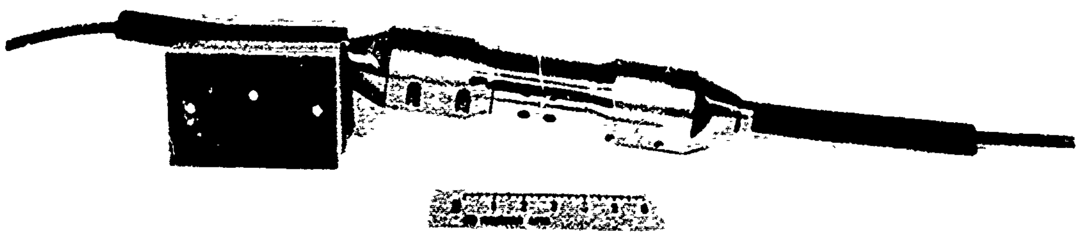


Fig. 2 - Hydrophone WX-"ERAY-1

2. CABLES

This chapter discusses the type of cable used for the array, a cable wiring diagram, the mechanical connectors, and the electrical connectors used on the ends of the cable sections.

2.1 Cable Type

In order to make this cable compatible with other ACODAC systems, Westinghouse was asked to use a 3/8" diameter seven conductor well logging armored cable. This cable was purchased from Vector Manufacturing Company and is designated by them as 738P. This cable was chosen since it had characteristics similar to cable that was being used in other ACODAC systems, but in addition it had better torque balancing characteristics as indicated by WHOI tests. Some of the important characteristics are given in Table 1.

Table 1 - Seven Conductor Armored Cable - Vector 738P

Conductors with Tape	OD = .208"
Armor	OD = .376"
DC Resistance	11 ohms/1000 ft.
Dialectric Strength	2000 Vdc
Lead Capacity	70 mmf/ft ± 10%
Weight in Air	240 lbs ± 10% per 1000 ft.
Weight in Water	196 lbs per 1000 ft.
Breaking Strength	12,000 lbs
Rotation per 1000 lb.	3.7° per ft
Insulation Resistance	1500 Megohms per 1000 ft. for 1 min. at 20°C

2.2 Cable Wiring Diagrams

A wiring diagram of the cables and transducers is shown in Fig. 3. Note that all cables are wired in an identical manner except for the cable below the bottom hydrophone. A break-away cable with eight wires is used between the lower clevis and the electronic package. Note that this conductor has eight leads. All cables are wired in an identical manner as shown in Fig. 4, except for the cable below the bottom hydrophone which is wired as shown in Fig. 5, and which contains the bottom clevis. The hydrophones are wired as shown in Fig. 6. As indicated in Section 3.1, the final units did not contain a reference oscillator. With the wiring method chosen, all cable sections and hydrophones are interchangeable.

The 1/8" diameter pins on the hydrophones and on the cable terminations were used to properly orient the connectors. Roll pins were initially used but they often were broken during the assembly of the split-couplers so solid pins are now used. Figure 7 shows a hydrophone with split-couplers on each end for attaching it to cable sections. The cable lengths used in the 1972 deployment are shown in Fig. 8. One spare set of cables were manufactured.

2.3 Electrical Connectors

A mechanical termination with associated electrical connections was desired which would join an array hydrophone to an array cable. The array assembly had to withstand wrapping over a winch drum of 44 inch root diameter under load.

Conventional ACODAC hydrophones are suspended on springs within cages about 1 foot diameter by 4 feet in length (see Fig. 13). However, these cages can not be wound onto a winch storage drum, so they have to be individually connected into the array during deployment operations and disconnected one at a time as they are brought aboard during retrieval operations.

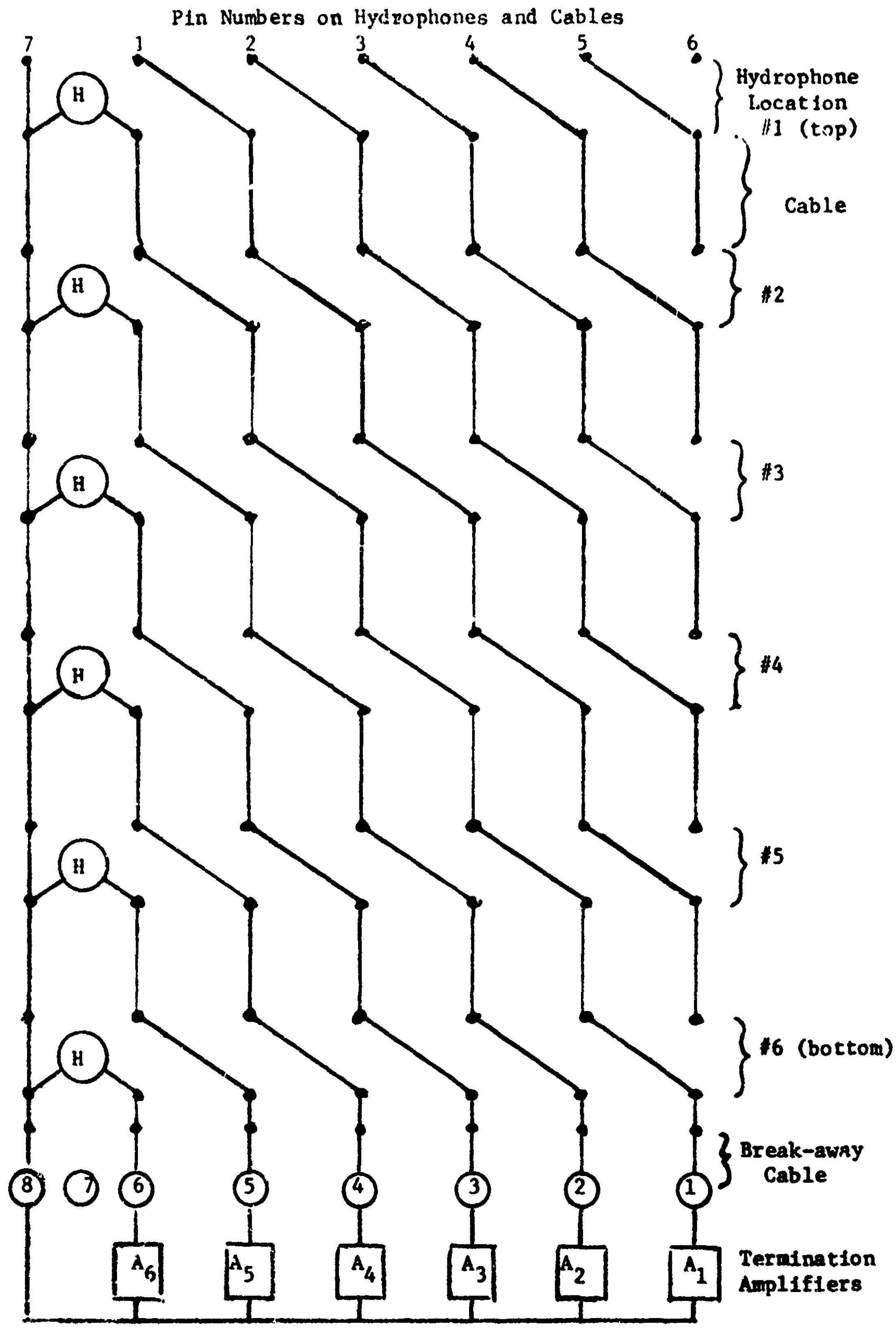


Fig. 3 - Array Wiring Diagram

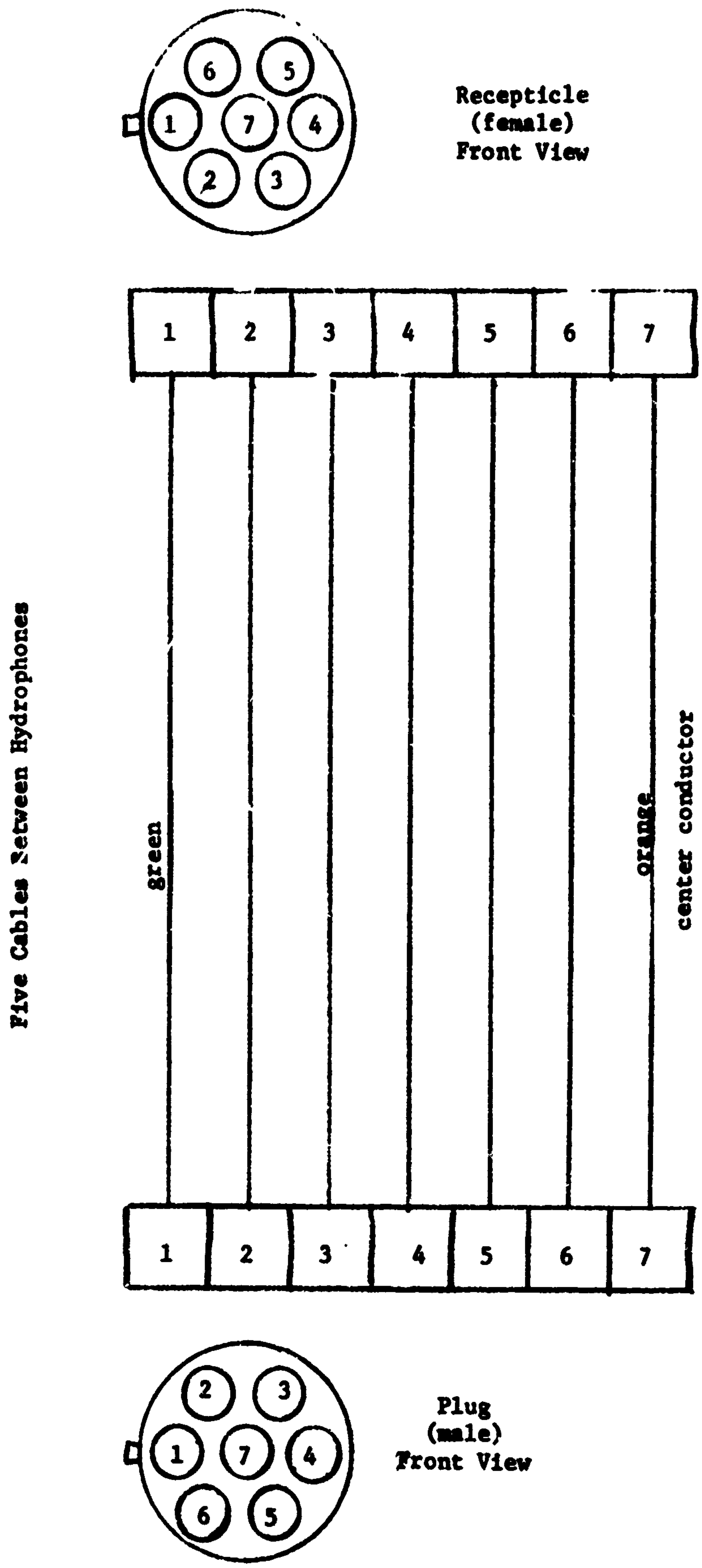


Fig. 4 - Cable Wiring Diagram

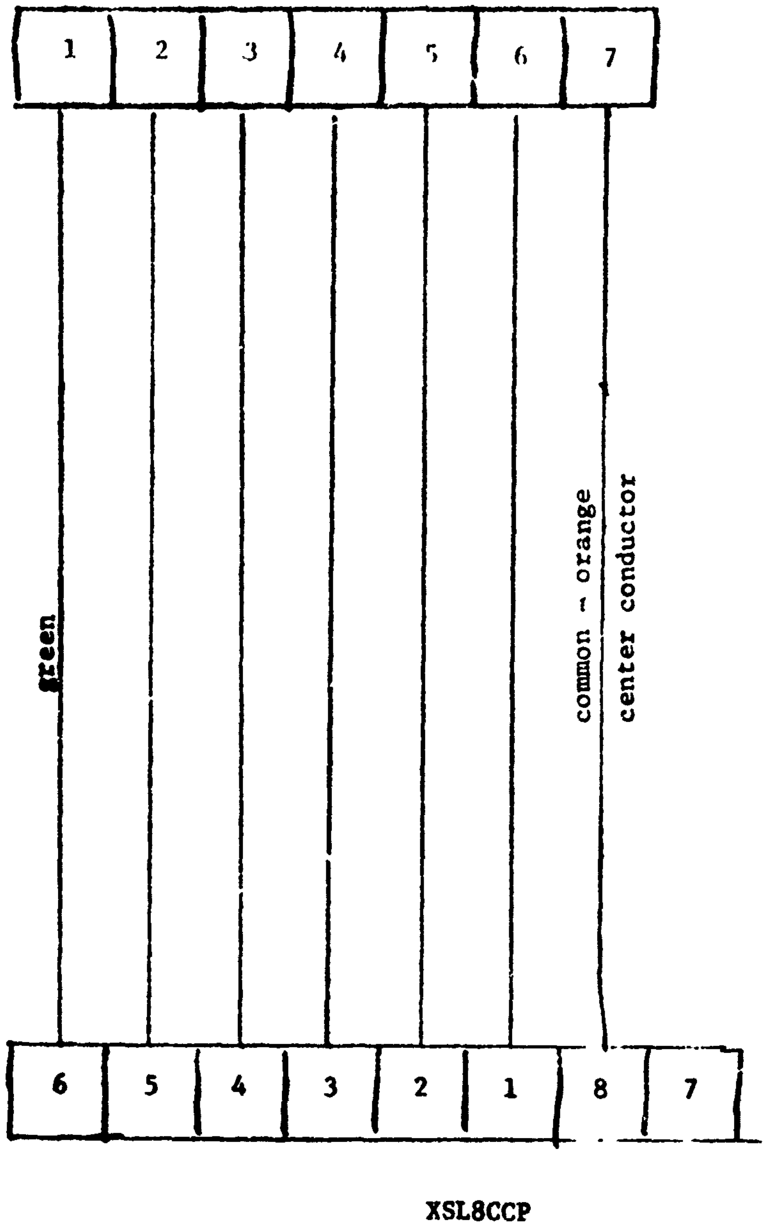


Fig. 5 - Cable Below Bottom Transducer

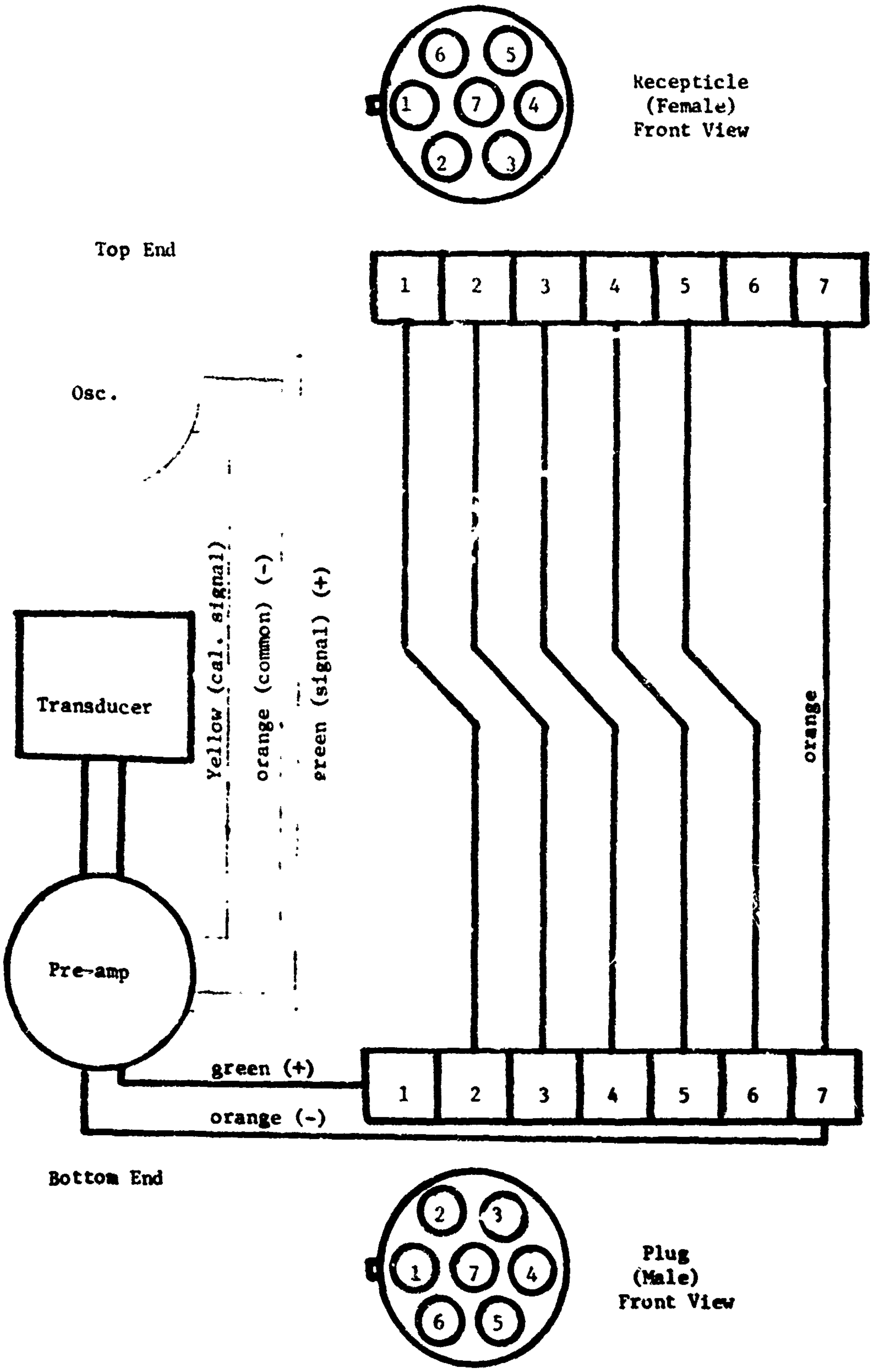


Fig. 6 - Hydrophone Wiring Diagram

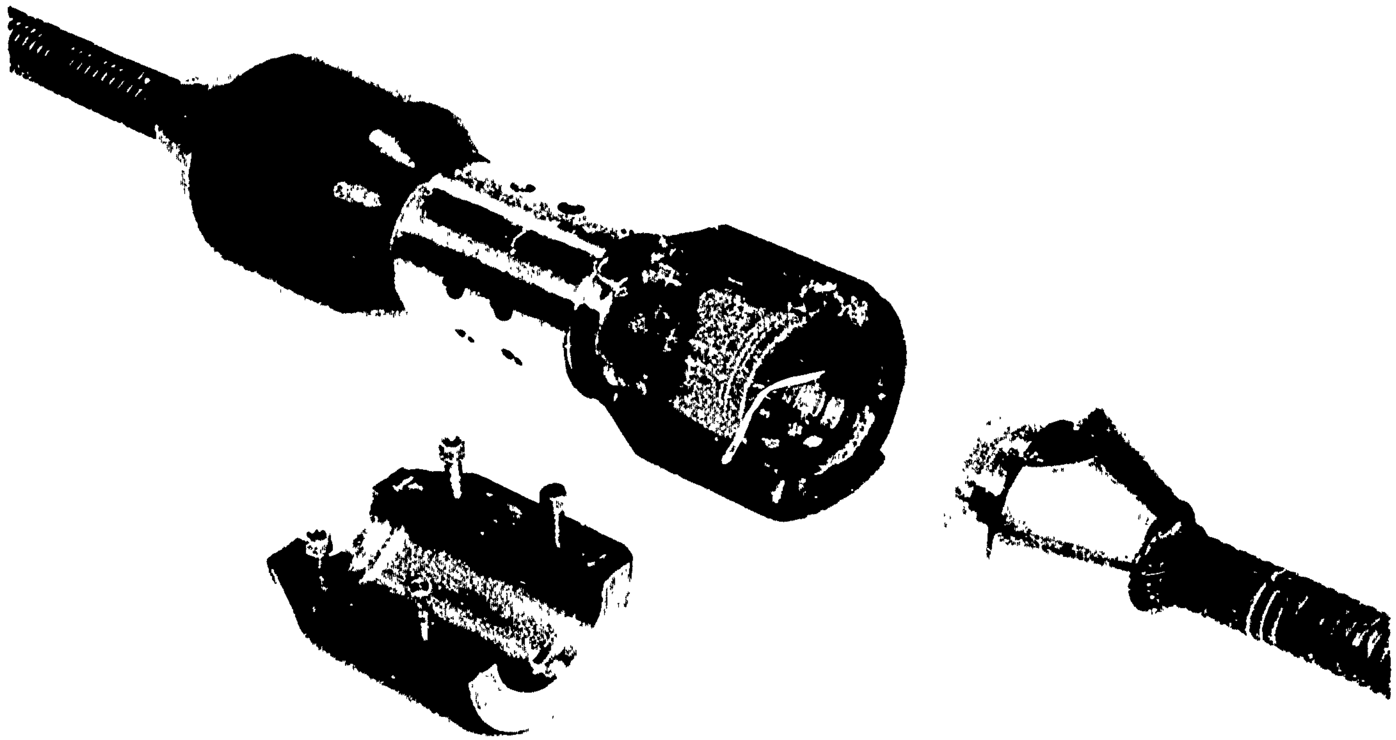


Fig. 7 - A Hydrophone with Split-Couplers at Each End for Attachment to the Cable

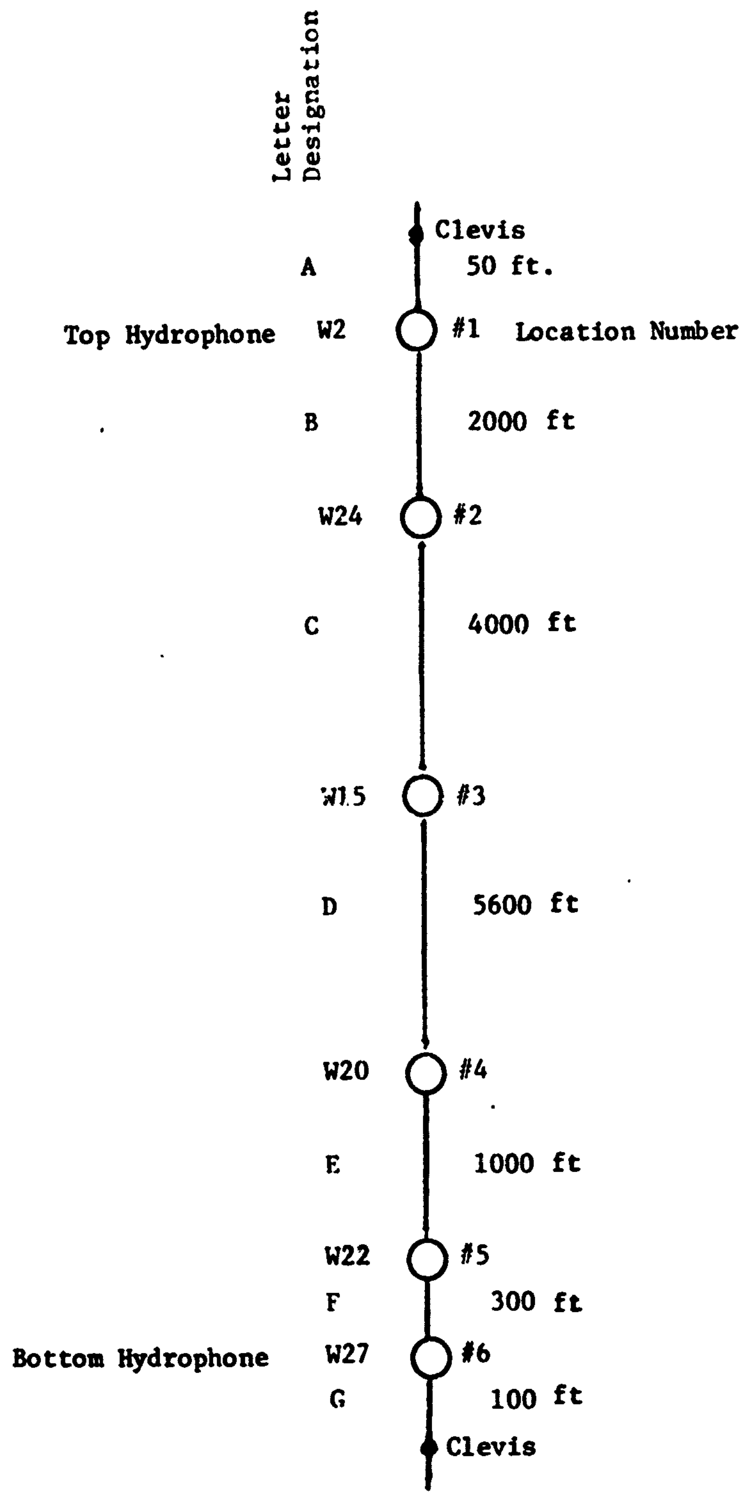


Fig. 8 - Cable Lengths and Hydrophones Used in November 1972 Deployment

Several methods of connecting the Westinghouse hydrophone to the electrical conductors of the cable were considered. Initially connectors, both single pin and multiple pin, were considered too bulky. A compact section of potted wire splices was designed for evaluation and a variety of splicing techniques were investigated. These splices consisted of joining the base electrical conductors by soldering or swaging and then potting the joint and a certain length of the conductor insulation with polyurethane, epoxy, or RTV (silicone rubber). A spacer disc was considered to separate the conductors so that the potting would fully surround them. The disc might serve as a back-up water seal or a type of stuffing tube for the conductors. The splice would be contained within split sleeves mechanically joining the hydrophone and the terminations.

Splices had the advantages of being relatively inexpensive and quite reliable. However, the splice would require meticulous care in disassembling to insure that the conductors were not damaged and could be re-spliced if a hydrophone were replaced. This would not be so difficult in the laboratory, but if a hydrophone required replacement aboard ship, such exacting requirements might prove time consuming and costly. Reassemble potting cure time would be 24 hours minimum and with the high humidity aboard ship, a void-free potting was questionable.

An alternate to this approach was to make permanent splices of the hydrophone conductors to the center of a 6 foot length of cable and then put electrical and mechanical connectors at each end. This would eliminate any need for field splicing. The connectors would fit into a housing identical in exterior shape to the hydrophone. This would retain the flexibility of the system. The connector housings and termination combination would use as many piece parts identical to the hydrophone splice and termination assembly as possible. Standard multipin underwater connectors were too bulky to fit within a package the size of the hydrophone so single pin connectors were investigated. This "remote connector" method doubled the number of array splices although it made it practical to replace hydrophones or cable sections on board ship.

A small compact waterproof polyurethane connector was designed (in consultation with H. Hamburg of Environmental-Electronics, Inc.) The polyurethane connector has an outside diameter of 5.1 cm and a length of 5.1 cm. The solder connections between the cable wires and the connector pins are potted with polyurethane. This design uses a molded-in-place O-ring seal with both axial and radial compression. The overall length was very close to the length of the original splice design. This design provides the capability of connecting and disconnecting the mechanical-electrical connector without requiring soldering or potting.

To prove the connector design, a prototype was fabricated. Hydrostatic tests were performed at the Westinghouse Oceanic Division, Annapolis, Md. The connector was cycled to 1000 psi, then to 10,000 psi and then twice more to 1000 psi. Connector resistance and insulation resistance tests were made at the minimum and at the maximum pressures during each cycle. The test performance was satisfactory. However, assembly and disassembly of the connector was rather difficult due to the slight interference fit used to insure a water-tight seal. This problem will be alleviated in the future by eliminating the circumferential interference fit which was found to be unnecessary since the O-ring seal provided a water-tight connection. For future deployments a fixture will be provided for holding the connector during assembly.

An outline of the final electrical and mechanical connector construction is shown in Fig. 9. The electrical connectors were constructed from tin-plated copper contacts and polyurethane (PRC-1538). Sealing the mating parts was accomplished by a molded-in-place O-ring on the interior surface of a long lip overhanging the male connector. A molded-in-place groove to complete the seal was made in the female connector.

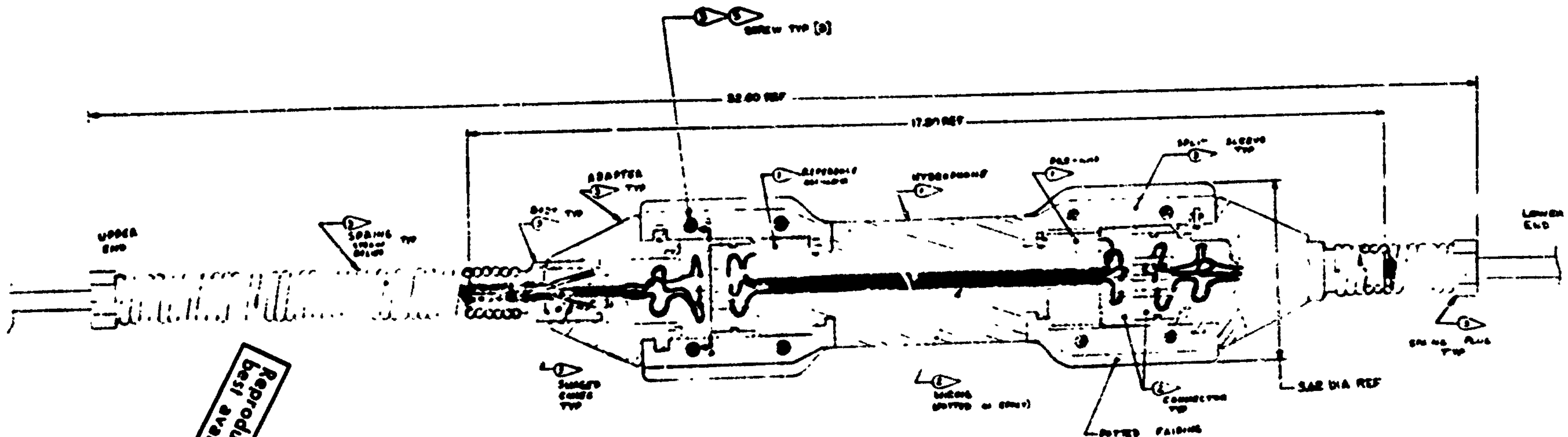


Fig. 9 - Hydrophone with an Electrical and Mechanical Connector at Each End

2.4 Mechanical Connectors

The concept for the cable mechanical termination was an adaptation from the WHOI ACODAC project design. The two layers of cable armor are swaged within the three cones of steel shown in Fig. 10 to secure the termination to the cable. The termination was modified to house the special electrical connector which was designed for this application.[5] A split coupler protects the electrical connector and mechanically couples the cable to the hydrophone unit (see Fig. 11(a)).

2.5 Clevis

At both extremities of the ACODAC array, the cable is terminated with a clevis assembly. In both cases a standard preformed rod "dyna-grip" clevis manufactured by Preformed Line Products Co., Cleveland, Ohio, is used.

At the upper end of this clevis-termination the electrical core of the cable is terminated along with the armor and potted, whereas at the lower end the core is brought free from the grip in a pigtail and terminated with a standard 8-pin underwater connector made by Vector Mfg. Co.

2.6 Stress Analysis

A stress analysis was performed on the hydrophone-split sleeve-termination assembly. This analysis showed all components capable of sustaining all anticipated tensile loads, but the bending stress effects on the hydrophone were questionable. In order to minimize the bending stress on the hydrophone, Micarta blocks were made to fit between each termination and the winch drum to provide support for the assembly, thus keeping the loads on the hydrophone almost entirely tensile in nature (see Fig. 2).

2.7 Tests in Plant

Prior to shipping the cable assemblies to Environ-Electronics for connector potting, they were tested for conductor resistance and insulation resistance as well as being tensile loaded to 5000 pounds. This loading was to insure that the swaged termination would not slip under load and that the electrical conductor would remain intact.

2.8 Tests at Sea

The first sea tests of the Westinghouse ACODAC were performed in November, 1972, off the coast of Miami. Launching and later retrieval of the array were accomplished smoothly as the hydrophone connector termination assembly allowed the winching operation to continue uninterrupted except for the addition of glass ball floats. The assembly and disassembly of the connectors were difficult in most instances due to the interference fit which had been provided so the polyurethane would be compressed by the split shell.

Two connectors were damaged; the cause was believed to be inadvertent sealing of the termination cable interface which prevented the cavity portion of the connector from flooding and equalizing the pressure surrounding the connector. Holes were thereafter drilled into the adapter to insure rapid flooding of this cavity in future deployments. EEI bonded the repaired and remolded connectors into their respective adapters.

2.9 Connector Recommendations

Several improvements will be made before the next deployment:

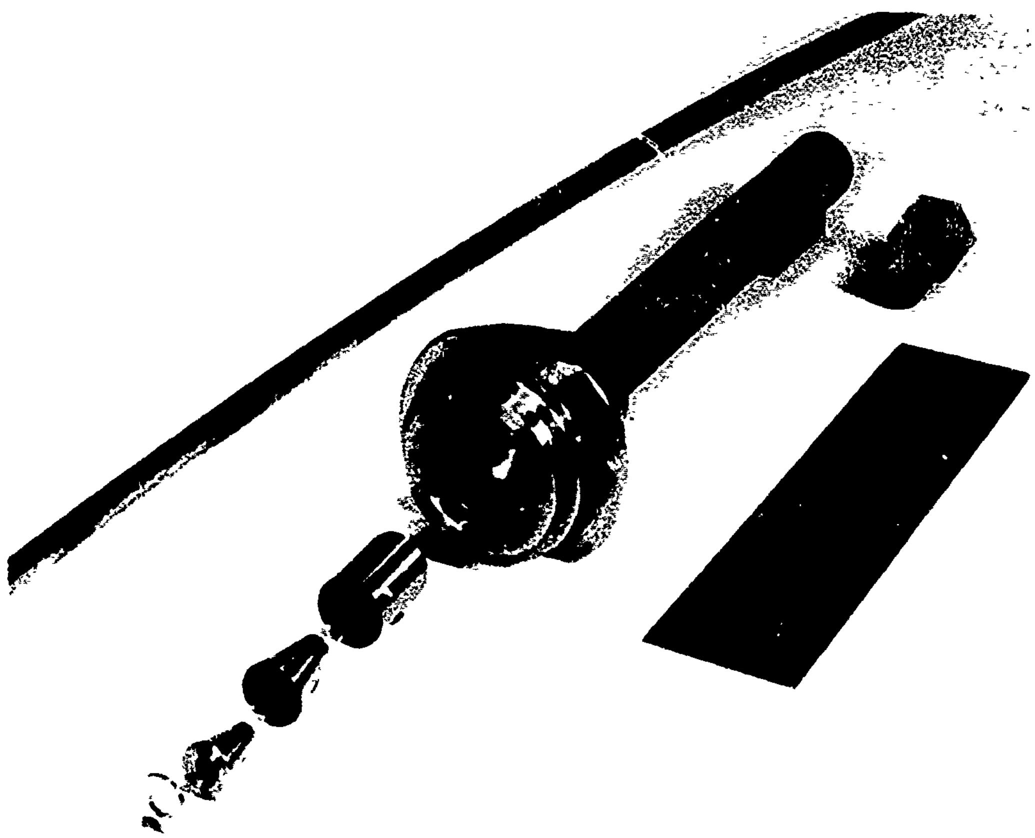
1) An assembly fixture will be constructed to facilitate assembly of hydrophone split coupler assembly.

2) The connector interference fit will be reduced in magnitude to allow for ease of assembly and disassembly but still retain proper sealing.

3) The EEI polyurethane potting priming procedures will be improved to provide better adherence to the connector and split sleeve components.

4) Future electrical connectors will be bonded into the conical mechanical connector. This will eliminate any problem of rotation of the electrical connector.

5) Connectors and cables should be tested in water prior to deployment. Pressure tests in salt water are recommended.



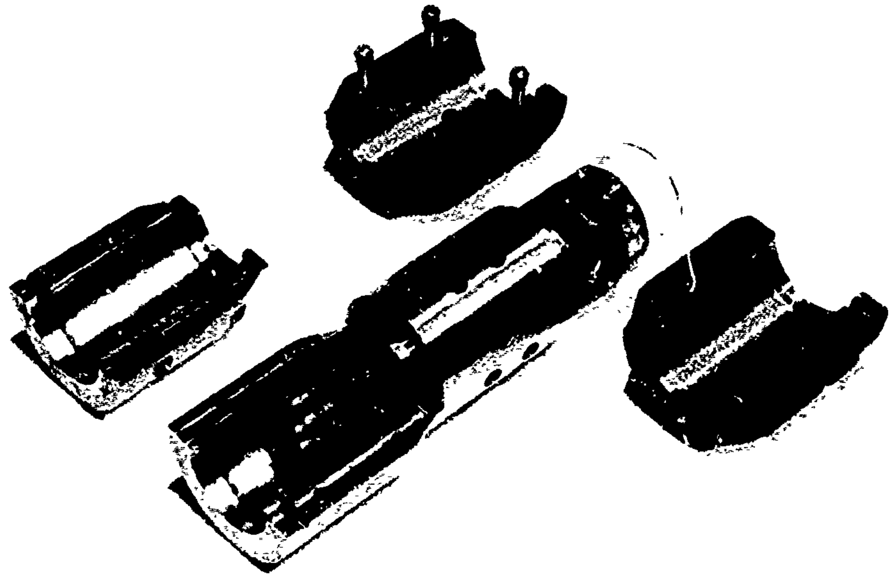
3. HYDROPHONE ASSEMBLY

A hydrophone assembly is shown in Fig. 11. It consists of a transducer with a preamplifier at one end and a reference oscillator at the other. A connector is potted to each end. The calibration oscillator gave problems at high ambient pressures and was eliminated. The characteristics of the WX-VERAY-1 hydrophone are given in Table 2. The acoustic properties are discussed in Section 6.

The hydrophone has a high sensitivity to dynamic pressure and a low sensitivity to acceleration. The unit was designed so that the entire array of hydrophones can be wound directly onto a drum as the cable is reeled in. It is felt that this would facilitate deployment and retrieval of a line array of units. Figure 12 shows a reel containing a 13,050 ft. array with six hydrophones. Figure 13 shows the size of a conventional hydrophone for comparison. Figure 2 is a view of a single hydrophone attached to a cable. A pair of micarta blocks were used to avoid bending stresses as the unit was wound on the drum. The split cylindrical couplers at each end protect the electrical connectors and preamplifier and provide a strong mechanical connection between the cable and the hydrophones. A fixture makes it convenient to remove or assemble the split cylinders while the water-tight electrical connectors are being held tightly together. The hydrophones have a male connector on one end and a female recepticle on the other. They are all wired alike so that hydrophone units can easily be interchanged or replaced. All of the cable sections are wired alike so they also can be easily interchanged, replaced, or pluged together.

3.1 Hydrophone

A cross-sectional view of the hydrophone without the preamplifier or connectors is shown in Fig. 14. It consists of a ceramic cylinder, 9, held on a spool shaped member, 2 and 4. The spool is supported in the



(a) Unit with Split Couplers

(b) Connectors on Ends of Unit

Fig. 11 - Hydrophone WX-VERAY-1

Table 2 - Hydrophone WX-VERAY-1 Characteristics

Diameter	6.35 cm ± 0.2 cm
Length	22.4 cm ± 0.5 cm
Weight	1,810 gms ± 20 gm
Sensitivity	-127 dBV/μPa (-27 dBV/μB)
Acceleration Response	-57 dBV/mg or less
Acceleration Response/ Sensitivity -	70 dB re 1 μPa/mg
Frequency Range	10 to 330 Hz
Noise Level	Below the lower Wenz ambient noise curve (see Fig. 32)
Operating Depths	0-15,000 ft.
Operating Temp. Range	0° to 30°C
Dynamic Range	60 dB
Tensil Strength	2720 kgm (6000 lbs)

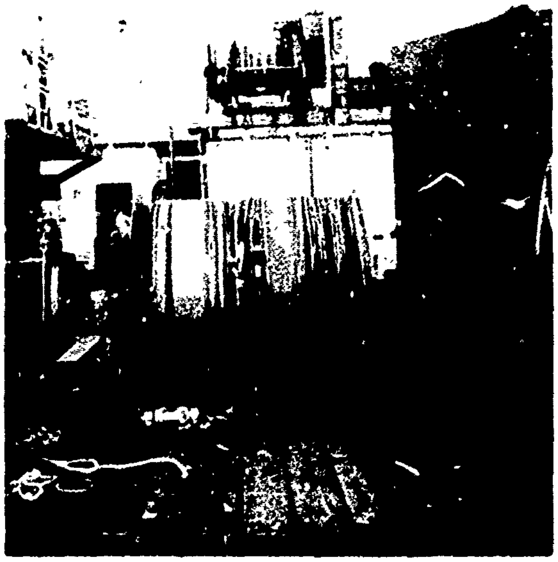


Fig. 12 - Reel Containing 13,050 ft. of Cable and Six Hydrophones

Fig. 13 - Conventional Hydrophone

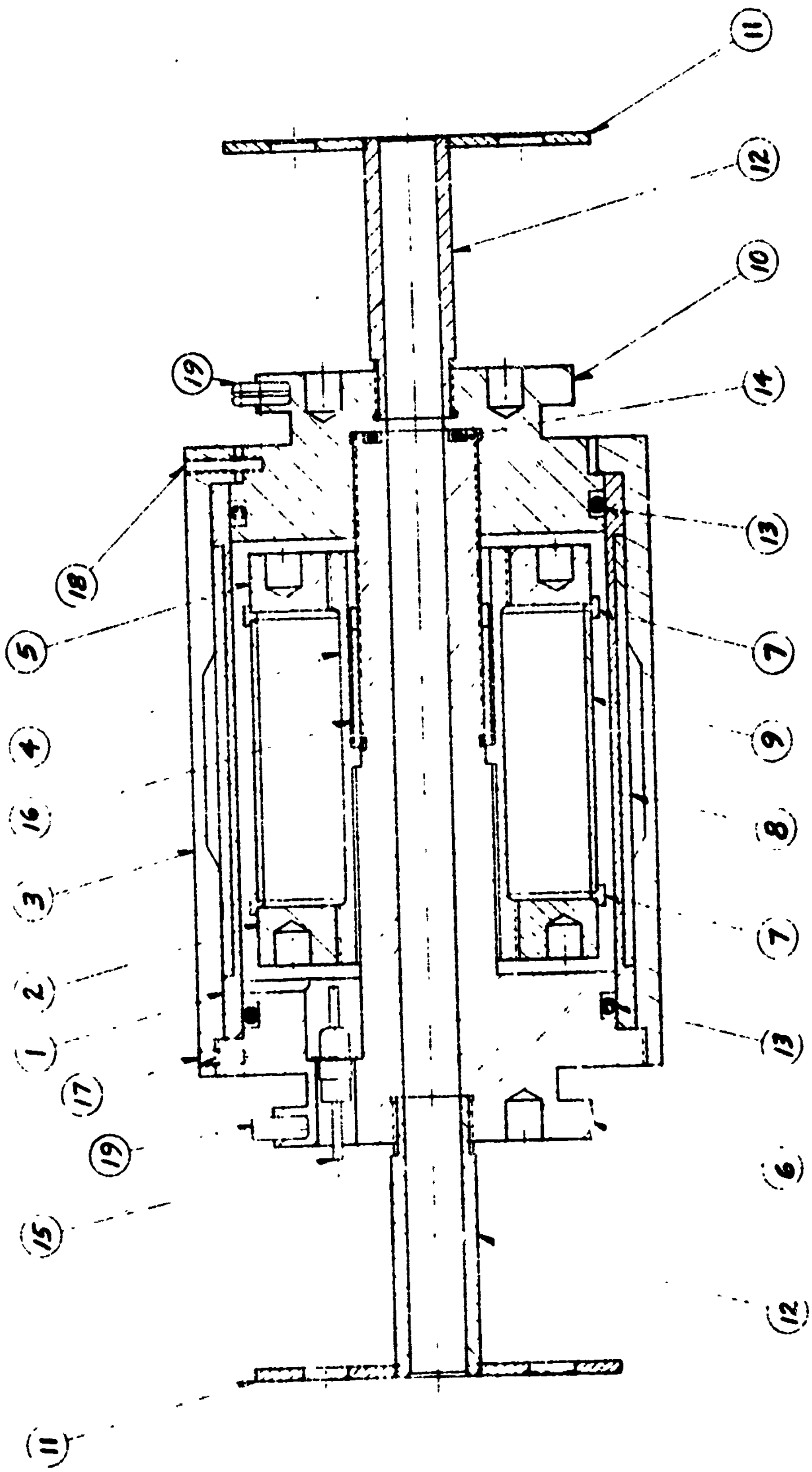


Fig.14 - Cross Sectional View of Hydrophone

center in order to have a low sensitivity to acceleration.[1] The space on both sides of the cylinder is filled with silicone oil. The oil is contained by a boot, 8, and "O" rings, 13, to prevent leakage of oil. The connectors are attached to the disks, 11. The preamp is potted around 12 between 6 and 11 and is connected to the ceramic cylinder by two feedthrough bushings, 15. The calibration oscillators are potted around 12 between 10 and 11. The leads from one connector to the other go through the center hole.

Figure 15 shows a partly assembled hydrophone. The "O" rings and ceramic cylinder are visible. The electrode geometry is evident on the two cylinders in the foreground. On the first set of units built, small amounts of sulfur from the butyl boots reacted with the silver electrodes to produce a black silver-sulfide. This is evident on the cylinder on the right side of Fig. 15. On later units gold plated nickel electrodes and PVC (polyvinylchloride) boots were used to eliminate this problem. Figure 16 shows a PVC boot before and after mounting on a cylinder.

An exploded view of the entire hydrophone is shown in Fig. 17. At the left side of the figure the two feedthrough bushings are shown. The output leads from the ceramic cylinder are connected to these. The input terminals of the potted preamplifier are connected to the other ends of these bushings. Two small check valves are used to facilitate filling with oil.

The inside of the ceramic cylinder was filled with Dow Corning 200 Silicone Fluid because it is three times as compliant as castor oil. Figure 18 shows the compressibility as a function of pressure. A 350 Cenistoke fluid was used. Also, the thermal coefficient of viscosity of this silicone oil is low compared to castor oil; see Fig. 19.

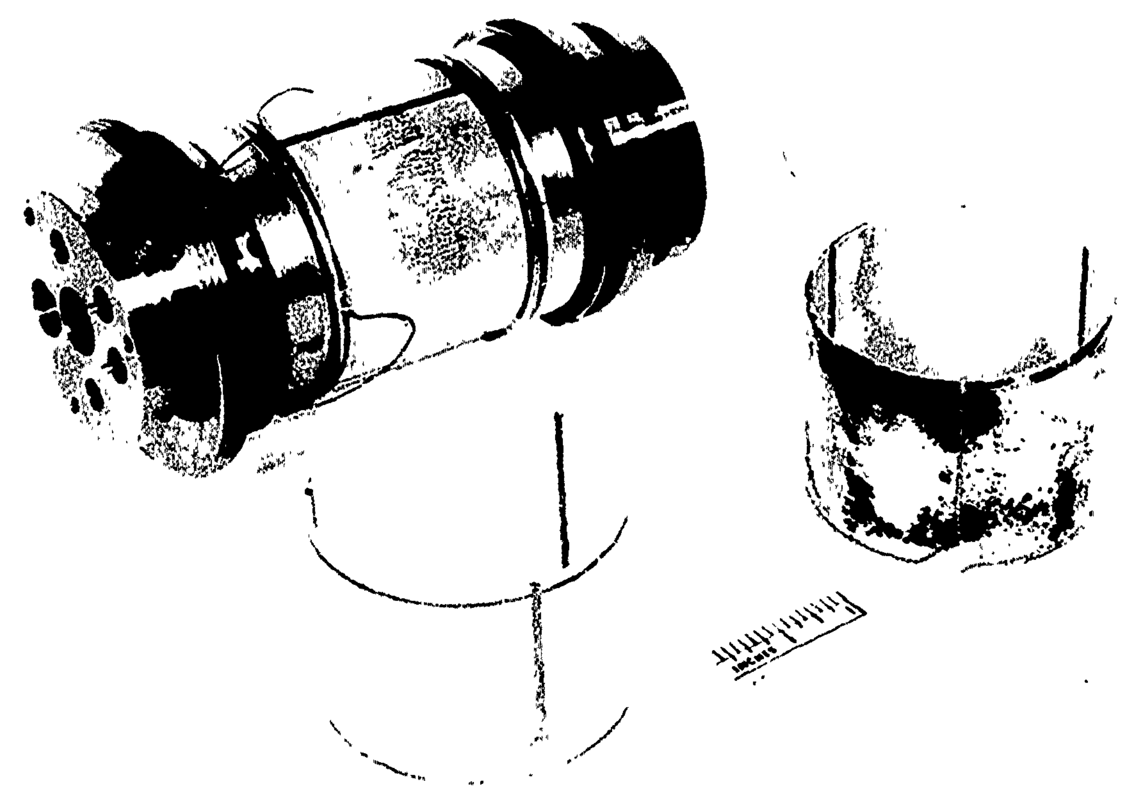


Fig. 15 - Partly Assembled Hydrophone and Two Ceramic Cylinders

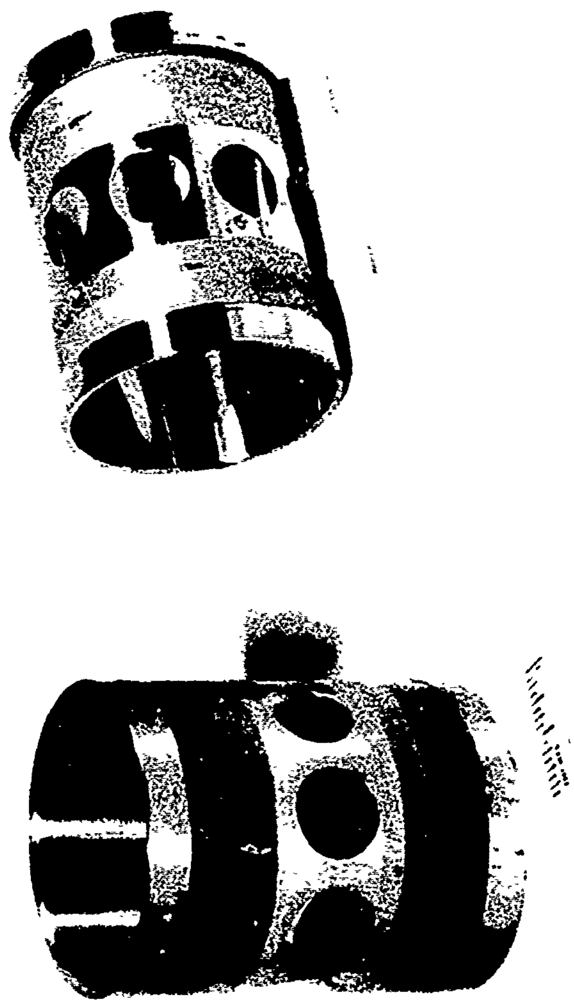


Fig. 16 - PVC Boot Before and After Being Mounted on a Stainless Steel Cylinder

RM-59797

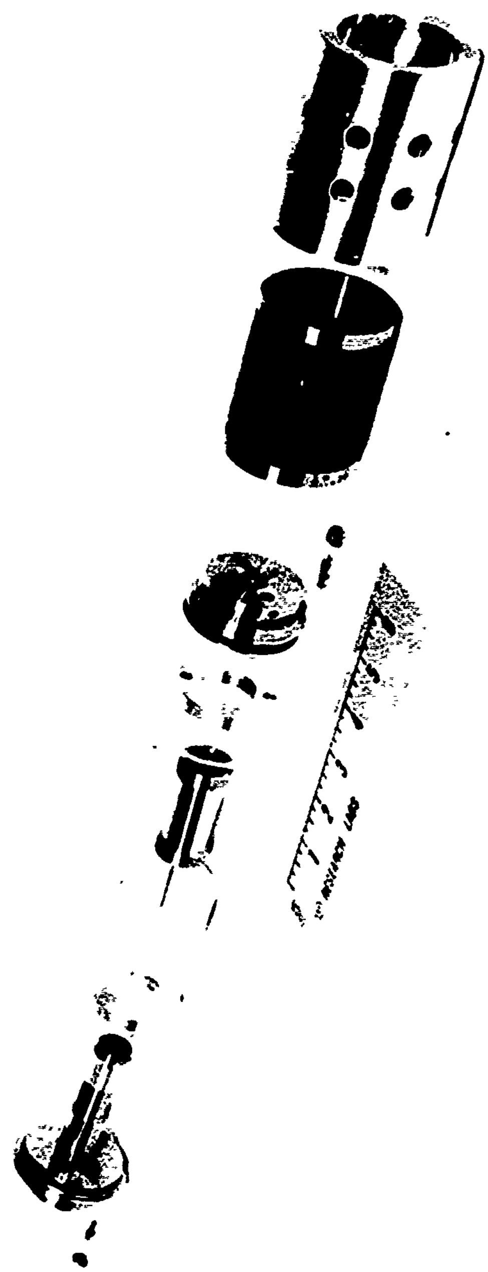


Fig. 17 - Exploded View of WX-VERAY-1 Hydrophone

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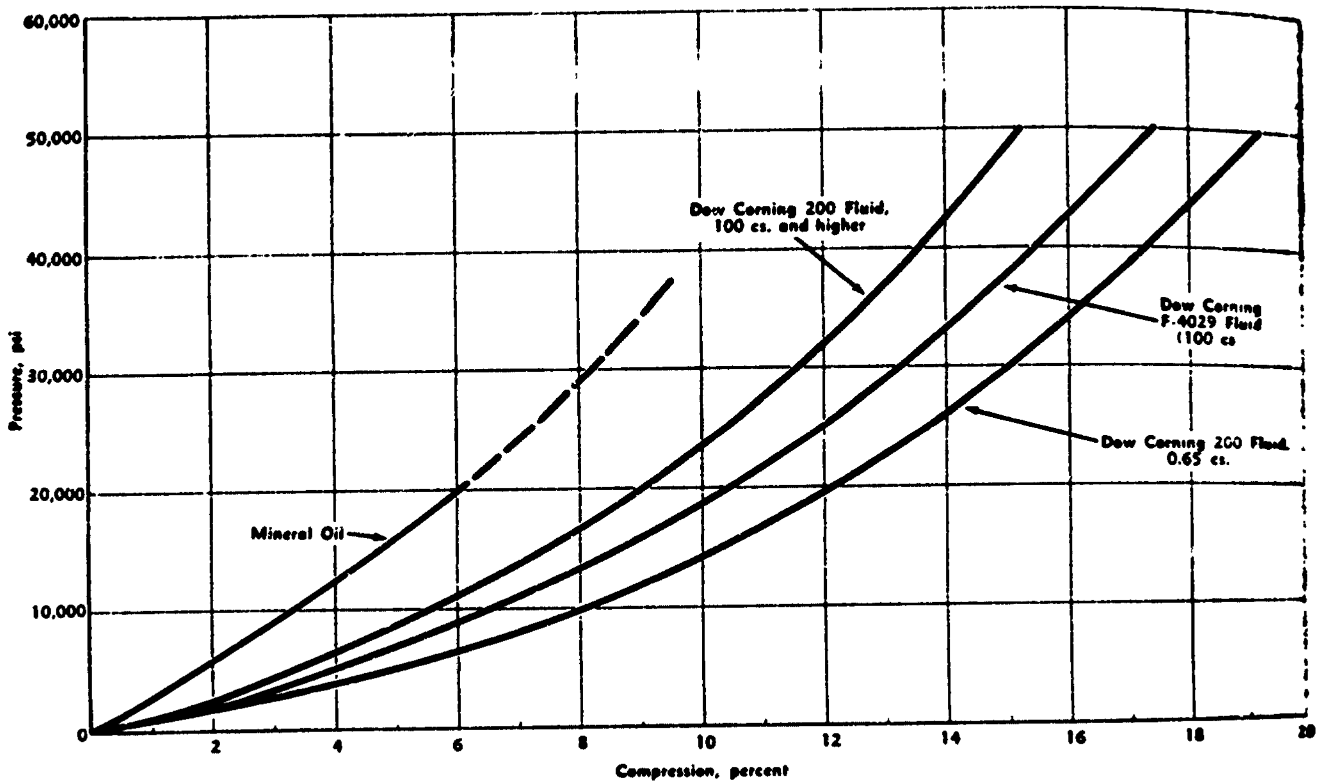


Fig. 18 - Compressibility of Silicone Fluids and Mineral Oil

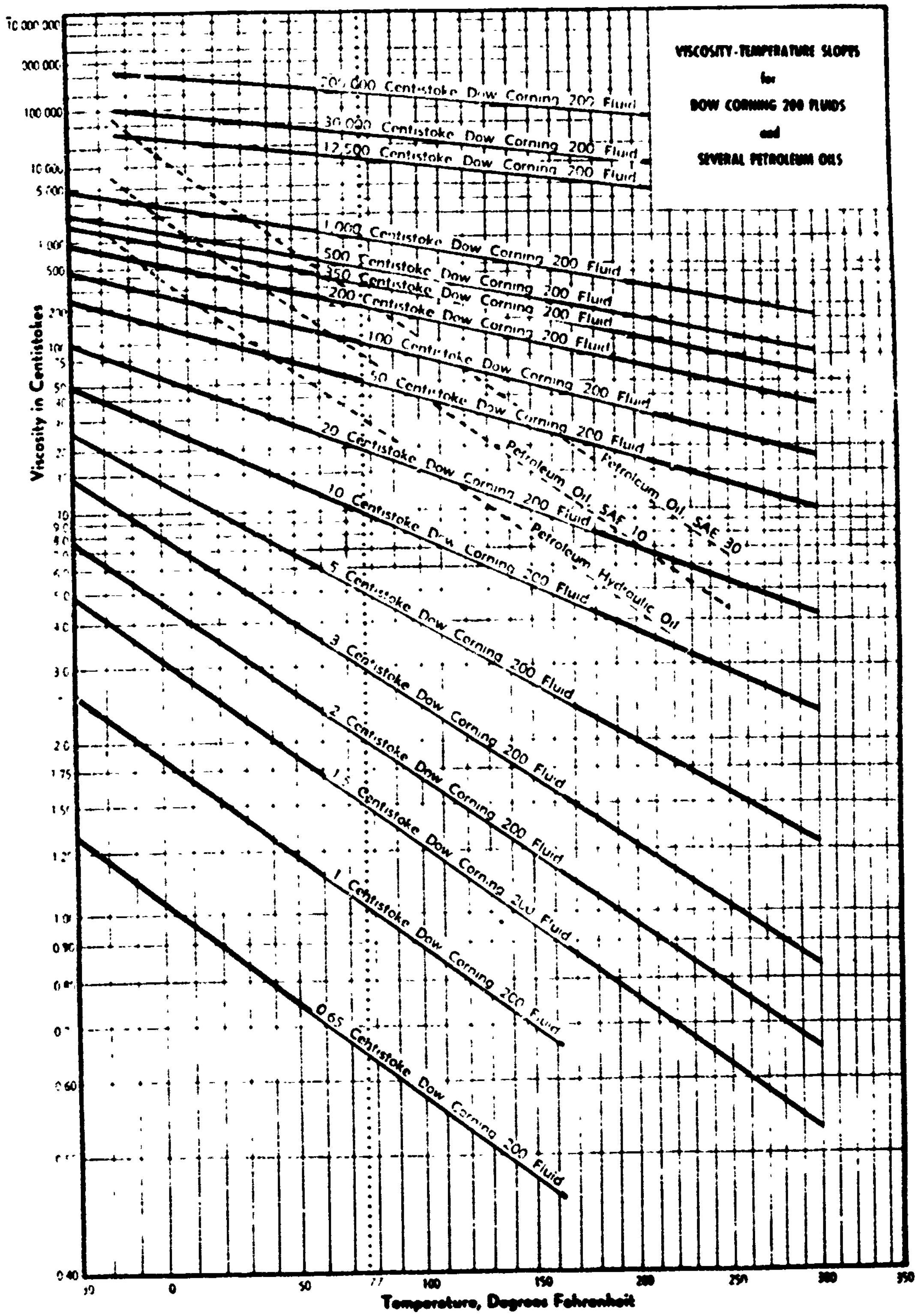


Fig. 19 - Viscosity of Dow Corning 200 Silicone Fluid

3.2 Preamplifier

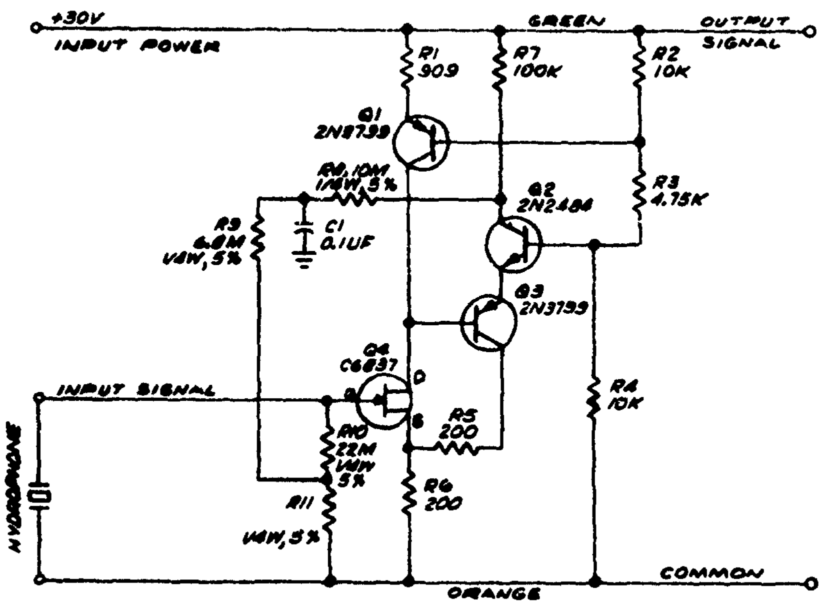
The preamplifier in this system is essentially a voltage-to-current converter with high input impedance, a conversion gain insensitive to parameter variations, good noise performance, and the capability of being powered from the output signal line. It is potted in polyurethane and located adjacent to the cylindrical transducer.

The circuit in Fig. 20 consists of a JFET transistor, Q4, bipolar transistor, Q3, feedback pair with series feedback, R6. A current source load for the JFET transistor, Q1, R1, and a relatively large value of series resistance, R6, are used to achieve a high loop-gain resulting in at least 40dB of negative feedback. A common emitter transistor stage, Q2, is used to couple the output signal, as a current, to the signal/power line. Resistors R7-R11 provide negative feedback bias to Q4. Resistors R2-R4 form a voltage divider to establish bias voltages for the circuit.

The circuit configuration is such that the single capacitor, C1, used can be a monolithic ceramic unit which is capable of withstanding the high pressure environment. Resistors below 1 megohm are of metal film on ceramic rod construction which change very little under pressure. Resistors above 1 megohm are 5% tolerance carbon resistors and are used in such a way that value changes due to pressure do not affect circuit operation. The active devices are exposed to the pressure environment, i.e., the covers of the metal cans are removed, but protected from contamination by a proprietary Westinghouse coating and silastic encapsulation.

The essential amplifier performance factors are:

Conversion Gain	500 μ mhos ± 3%
Input Impedance	22 MΩ resistive ± 20%
Output Impedance	above 10 kΩ resistive
Frequency Response	10 Hz to 300 Hz ± 1 dB
Noise Voltage (with Ⓦ hydrophone)	below the lower Wenz noise curve
Power Required	14 mA at 30 Vdc ± 1mA



NOTES:
1. R11 SELECTED TO BIAS Q2 & Q3 AT I_C = 50UA.
2. ALL TRANSISTOR CHIPS ARE PASSIVATED
3. R1 THRU R7 ARE 1/8W 1% METAL FILM RESISTORS ON SOLID DIELECTRIC RODS.
4. C1 IS A MONOLITHIC CERAMIC CAPACITOR.
5. R8 THRU R11 ARE ½ W 5% CARBON RESISTORS

Fig. 20 - Preamplifier Circuit

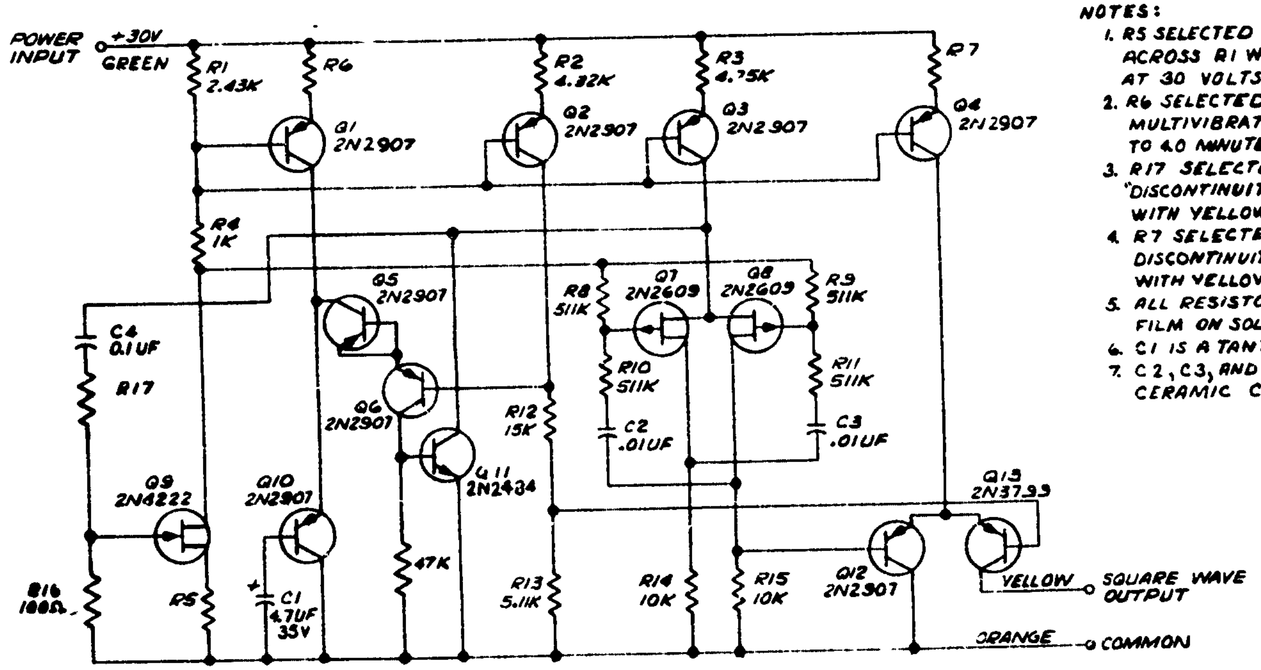
Resistor R11 was selected to bias Q2 and Q3 at 50 μA. On the original units a yellow lead was brought out so the calibration signal could be fed to the source of Q4. When the calibration circuit was abandoned, this lead was eliminated.

The entire preamplifier was potted in polyurethane PR-1538 obtained from Products Research & Chemical Corporation. The material was outgassed in a vacuum system after mixing and then poured into a mold that surrounded the circuit. The unit was pressurized to 45 psi with dry nitrogen and baked 24 hours at 65°C.

3.3 Calibration Oscillator

A reference oscillator was designed and built for generating a calibration signal automatically each time the power was turned on. The circuit is given in Fig. 21 and an unpotted unit is shown at the bottom of Fig. 24. It was designed to deliver a 20 Hz square wave signal of 1 mV peak to the input stage of the preamplifier for 3.5 to 4 minutes after dc power was applied to the hydrophone assembly. This circuit contains 13 transistors. These commercially available transistors had the tops removed from the cylindrical cans and were passivated. After wiring, the entire assembly was potted in polyurethane. Upon pressure cycling at room temperature many of the circuits failed. The time and cost of determining which components were at fault was not warranted and hence the use of the reference oscillator was abandoned.

Figure 22 provides a block diagram of the calibrator unit. When dc power is applied the MV (multivibrator) starts and the timer cycle is initiated. The 20 Hz MV switches a calibrated current into the source of the preamp FET. After 3.5 to 4 minutes the timer turns the MV off. The circuit was designed so that the dc current drawn during each half cycle changed by less than 0.2%. Any changes would be superimposed on the preamp output signal. Consequently, the circuit was designed to have a relatively large output signal to minimize the



NOTES:
1. R5 SELECTED TO PRODUCE 5.00 VOLTS ACROSS R1 WITH SUPPLY VOLTAGE AT 30 VOLTS.
2. R6 SELECTED TO PRODUCE A MULTIVIBRATOR "ON TIME" OF 3.5 TO 4.0 MINUTES.
3. R17 SELECTED TO REMOVE "DISCONTINUITIES" IN SYSTEM OUTPUT WITH YELLOW LEAD DISCONNECTED.
4. R7 SELECTED TO PRODUCE 1 VOLT DISCONTINUITIES IN SYSTEM OUTPUT WITH YELLOW LEAD CONNECTED.
5. ALL RESISTORS ARE 1/8 W 1% METAL FILM ON SOLID DIELECTRIC RODS.
6. C1 IS A TANTALUM CAPACITOR.
7. C2, C3, AND C4 ARE MONILTHIC CERAMIC CAPACITORS.

Fig. 21 - Calibration Oscillator Circuit

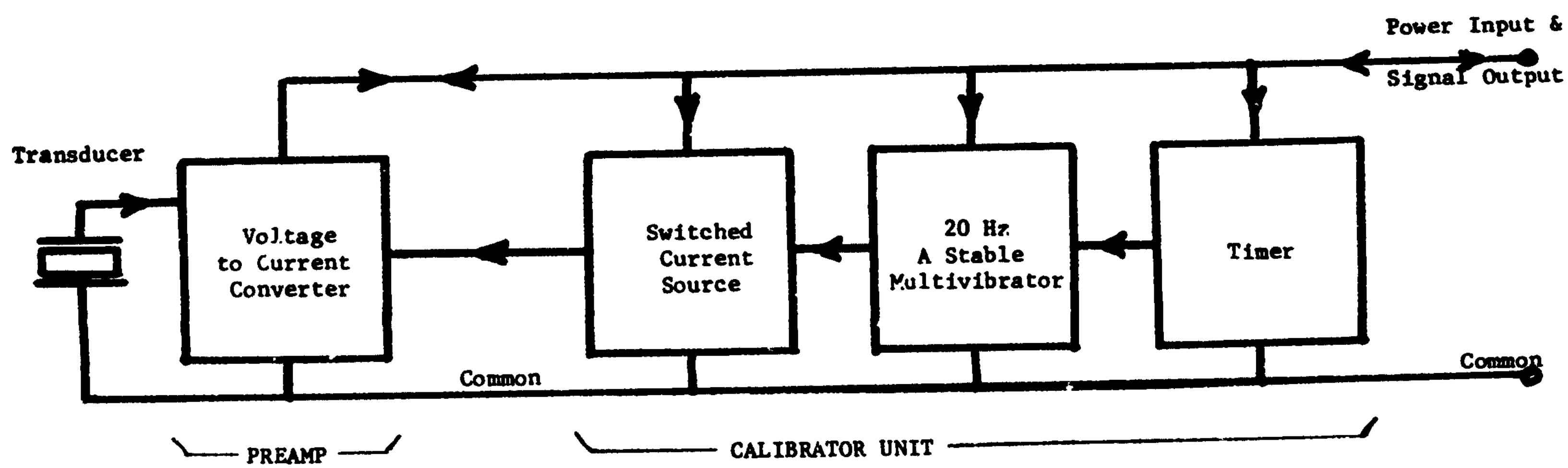


Fig. 22 - Block Diagram of a Transducer with Pre-Amp and Calibrator

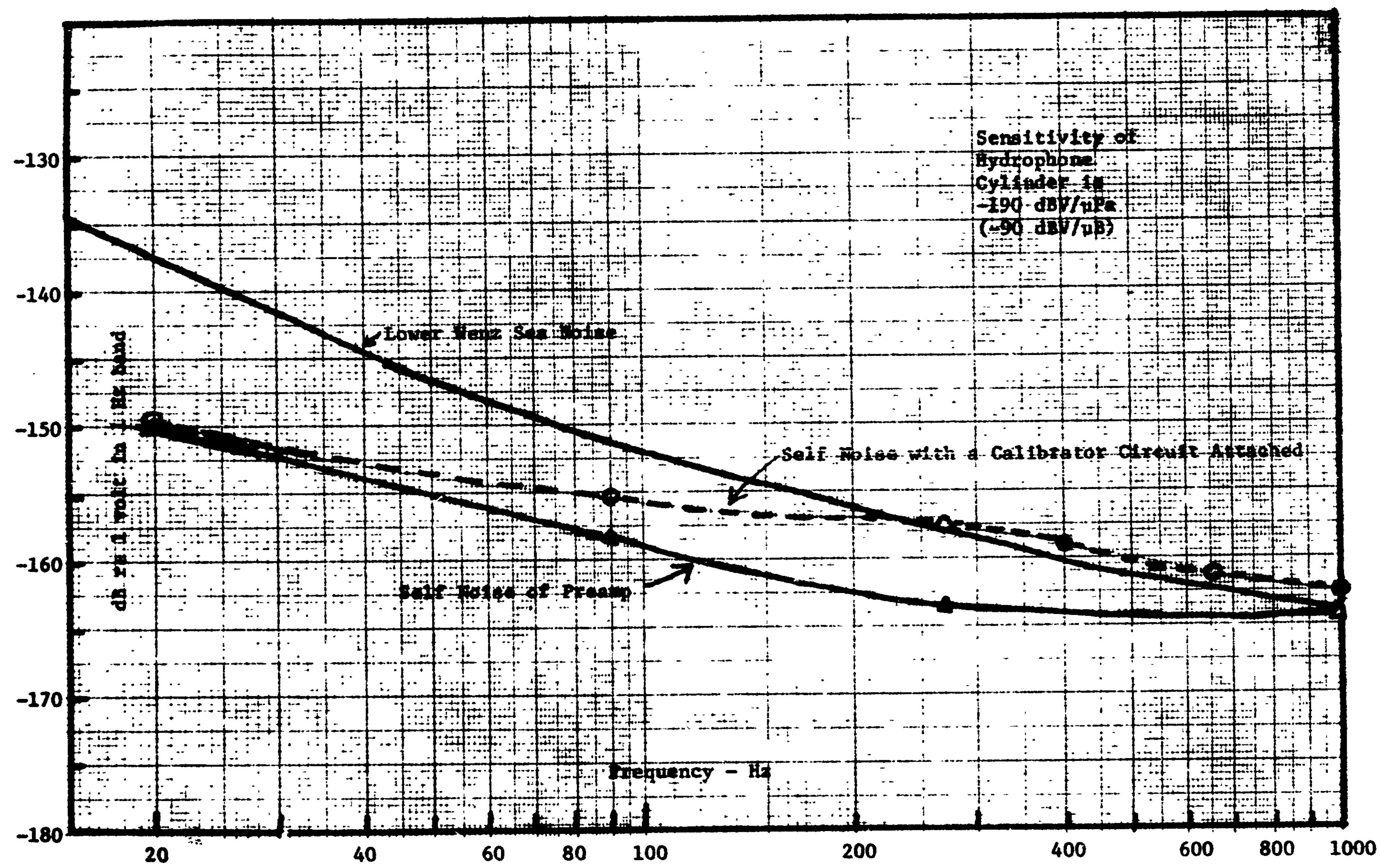


Fig. 23 - Increase in Preamp Noise Due to a Calibrator Unit

distortion produced in the output square wave from the preamp. Because of the manner in which the step attenuators were introduced in the tape amplifier, it was necessary to have the calibrate signal last for more than 3.5 minutes. This required a large value of C1 in the timing circuit.

Monolithic ceramic capacitors were used for C2, C3, and C4. A hermetically sealed tantalum capacitor was used for C1 but it was later found that some of these units contained voids. Using epoxy dipped tantalum or the more expensive monolithic ceramic capacitors was considered.

Self noise tests were made on the preamp both with the oscillator circuit disconnected and connected. At 20 Hz no noise was added due to the oscillator, but at 300 Hz the oscillator circuit increased the self noise of the system about 6 dB. The typical response curve of Fig. 23 shows the increased noise that resulted from the calibrator unit.

3.4 Electrical Connectors

Electrical connectors are potted onto both ends of the hydrophone. These seven pin connectors are identical to the ones on the cables. A male connector is used at the bottom end of the hydrophone and a female connector at the top end. This avoids any possibility of the unit being inadvertently reversed.

When the connectors are assembled, Dow Corning #4 silicone dialectric grease is used in the "O"-ring groove to help provide a water-tight seal. The same grease is used on the outside of the male connectors to reduce friction between the split coupler and the polyurethane. A CRC lubricant spray is also used on the split cylinder to reduce corrosion.

4. TERMINATION UNIT

Inside the aluminum sphere, that contains the tape recorder and associated electronics, is a Westinghouse termination unit. The unit is shown at the top left of Fig. 24. It contains a power converter and a termination amplifier for each hydrophone.

The power converter unit shown in the center of the figure is located in the bottom half of the aluminum box. Six termination amplifiers are located in the top of the box. Each is mounted on a small circuit board. Two of these boards are shown mounted in the top right part of Fig. 24.

4.1 Termination Amplifiers

A schematic of a termination amplifier is shown in Fig. 25. The six units are alike except for the values of R1 and R2. The function of each termination amplifier is to supply dc power to an associated preamplifier[2], to receive a signal current from that preamp and to convert it to an output voltage. Since it was necessary to use a seven conductor cable for six hydrophones, one wire per hydrophone had to be used for both power and signal with the seventh wire serving as a common line for all channels.

For the November 1972 deployment, the cable lengths are given in Table 3. The resistance of each wire in the cable is 10 ohms $\pm$ 10% per 1000 ft. Figure 26 shows an ac equivalent circuit of the cables and the terminations of all six channels. The values of R1 were chosen so as to make the total resistance of each signal path equal to 280 ohms $\pm$ 10%. The equivalent dc circuits are shown in Fig. 27. The R2 values were chosen to make the dc voltage at each preamp 30 volts. Table 3 lists the R1 and R2 values of all amplifiers.

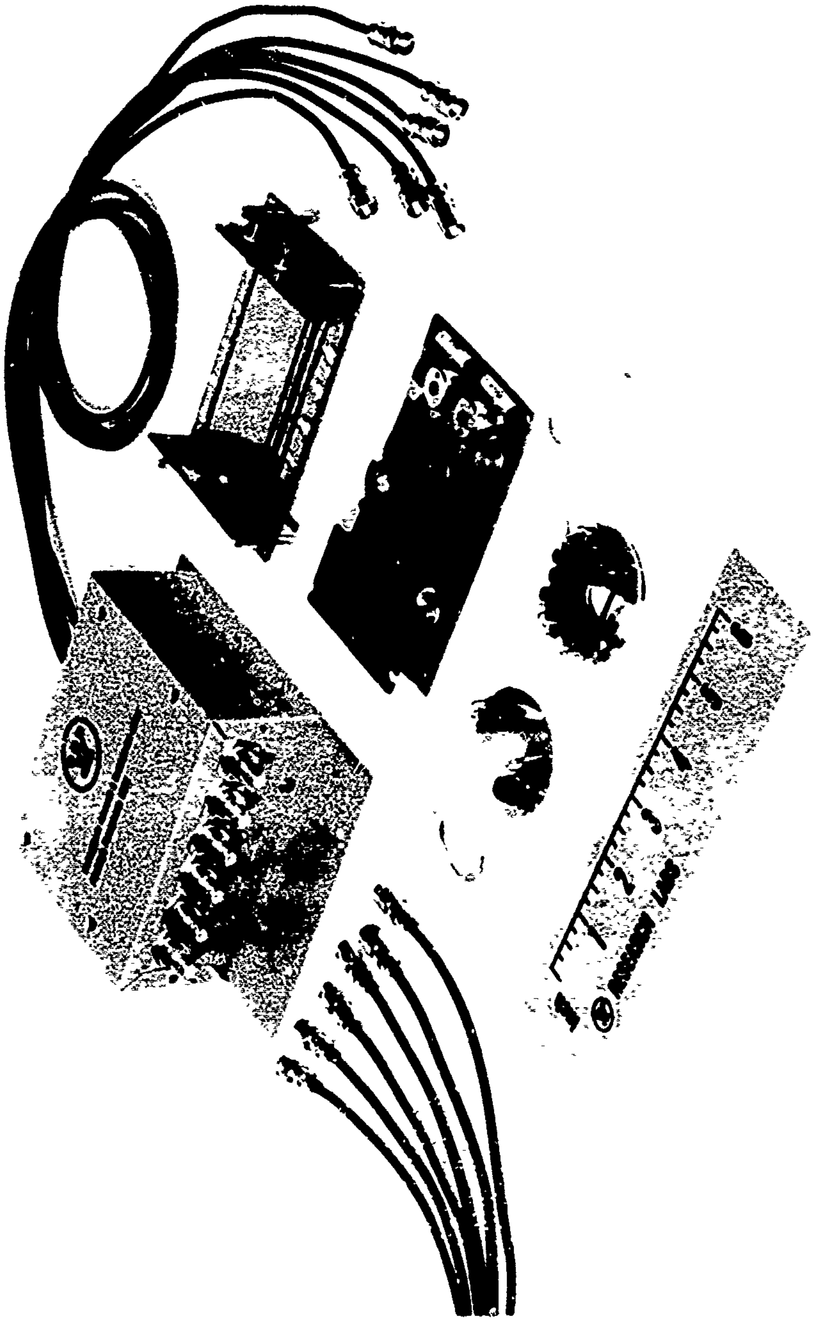


Fig. 24 - Termination Unit, Preamp and Calibration Oscillator Circuits

Dwg. 6209A87

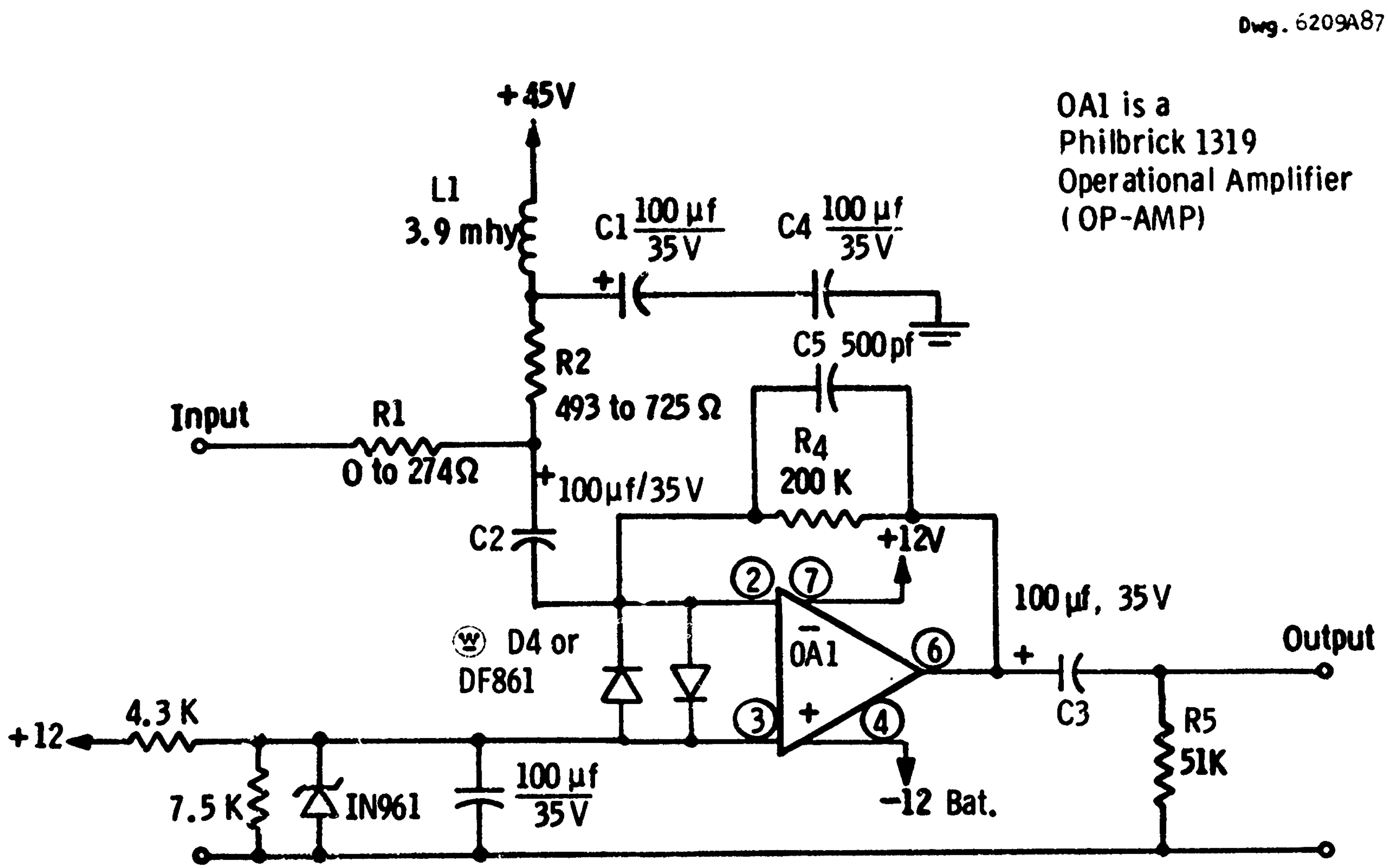


Fig. 25 - Termination Amplifier (Nov. 1972)

Dwg.6190A06

Table 3 - Resistance Values for Termination Amplifiers

Hydrophone Location & Amplifier Number	R1 ohms	R2 ohms	Cable Lengths feet	Designation
			50	A
1	0	493		
			2000	B
2	43	483		
			4000	C
3	133	537		
			5600	D
4	243	662		
			1000	E
5	274	794		
			300	F
6	274	725		
			100	G

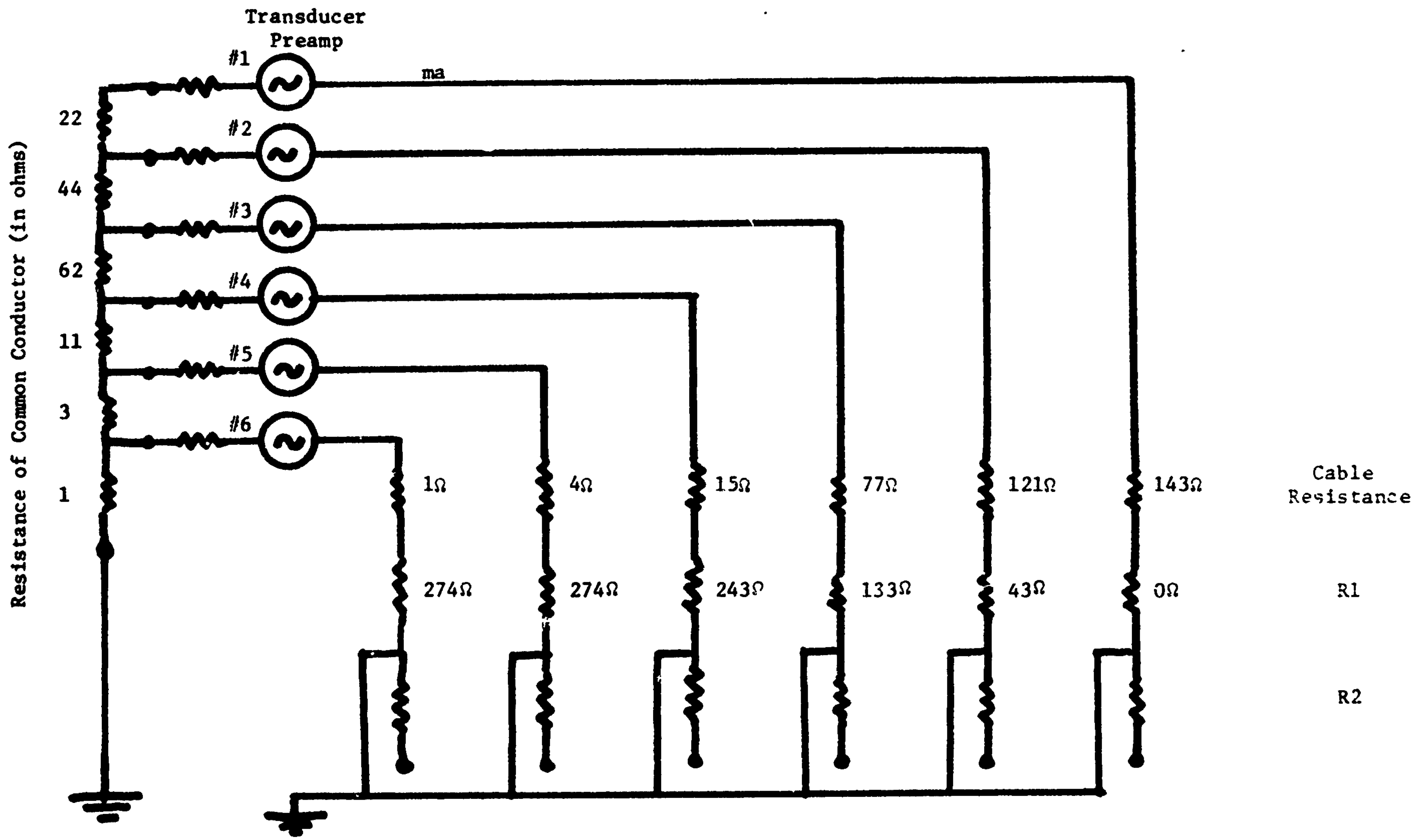


Fig. 26 - Equivalent AC Circuit

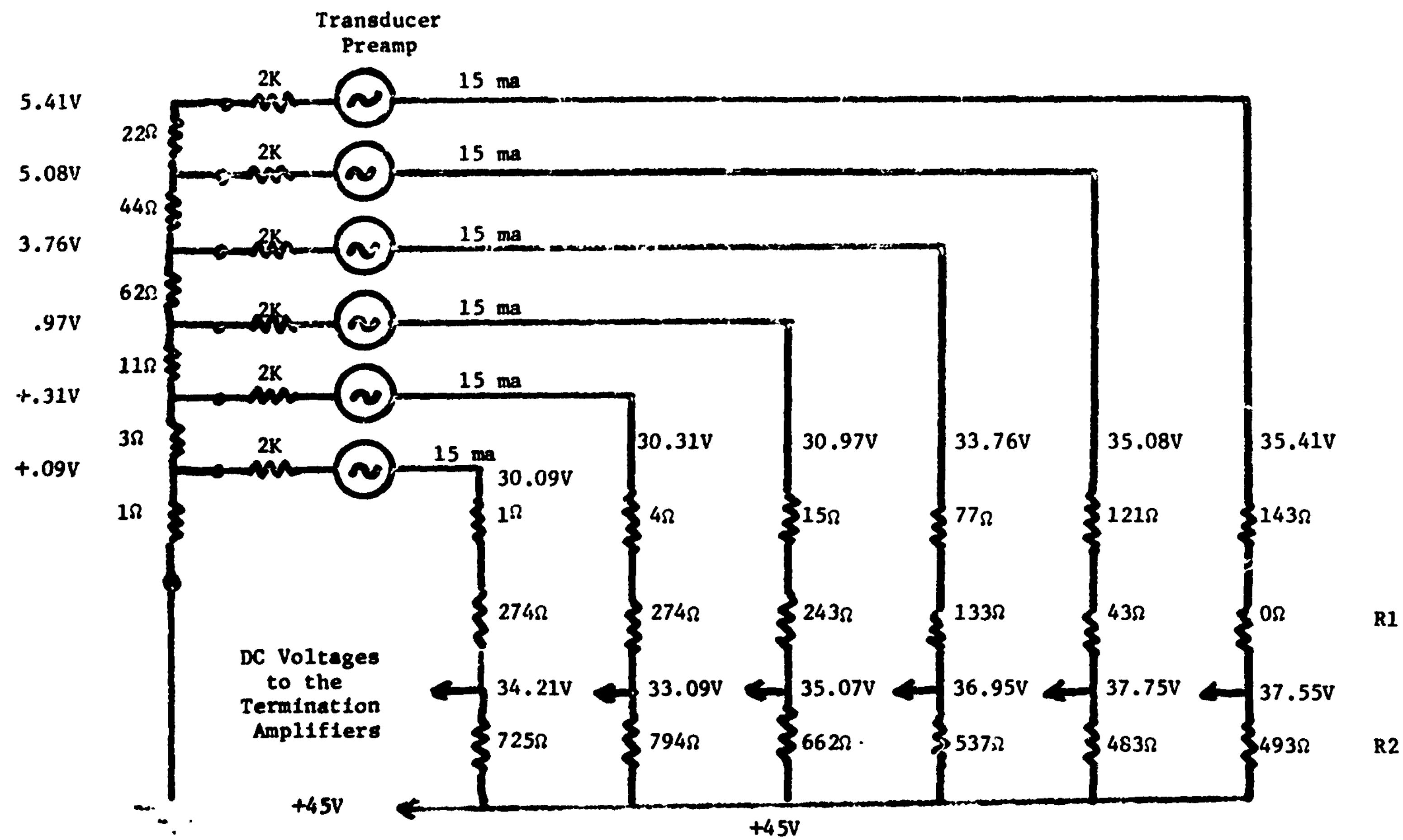


Fig. 27 - Equivalent DC Circuit
R2 values chosen to make dc
voltage at each preamp equal to 30V.

In Fig. 25, L1 and C1 form a low pass filter to reduce the 20 kHz ripple on the 45 volt converter output. C2 provides a low impedance path to direct the signal current into the summing junction of operational amplifier OA1. The pair of diodes provide a low impedance path for the charging and discharging of C2 during turn-ON and turn-OFF of the power source. R4 provides shunt negative feedback to provide a low summing junction impedance and stable current to voltage conversion gain equal in magnitude to R4. C3 provides dc isolation between the amplifier output and the tape amplifier input. R5 provides a dc charging path for C3. This resistance is large compared to the 5000 ohm tape recorder amplifier impedance. R3 is used to bias the OA1output 2 volts positive so as to properly polarize C3.

The overall system was designed to have a sensitivity of -29 dBV/μB and an output range from 1 mV to 1 V (60 dB) to match the capabilities of the recording system. The amplifier has a gain of 60 dB so the corresponding signal levels at the piezoceramic terminals are 1 μV to 1 mV. The maximum amplifier output is 4 volts before saturating.

Signals from the transducer as large as 1 V will not damage the input transistor. The sensitivity of the piezoelectric element alone is

$$-89 \text{ dBV}/\mu\text{B}$$

so a signal level as great as

$$+89 \text{ dB re } 1\ \mu\text{B} = +189 \text{ dB re } 1\ \mu\text{Pa}$$

will not damage the unit. If larger signals are anticipated, a pair of back biased diodes can be used across the input terminals. However, this will reduce the low frequency sensitivity and will also decrease the overall signal to noise ratio of the hydrophone.

4.2 Power Converter

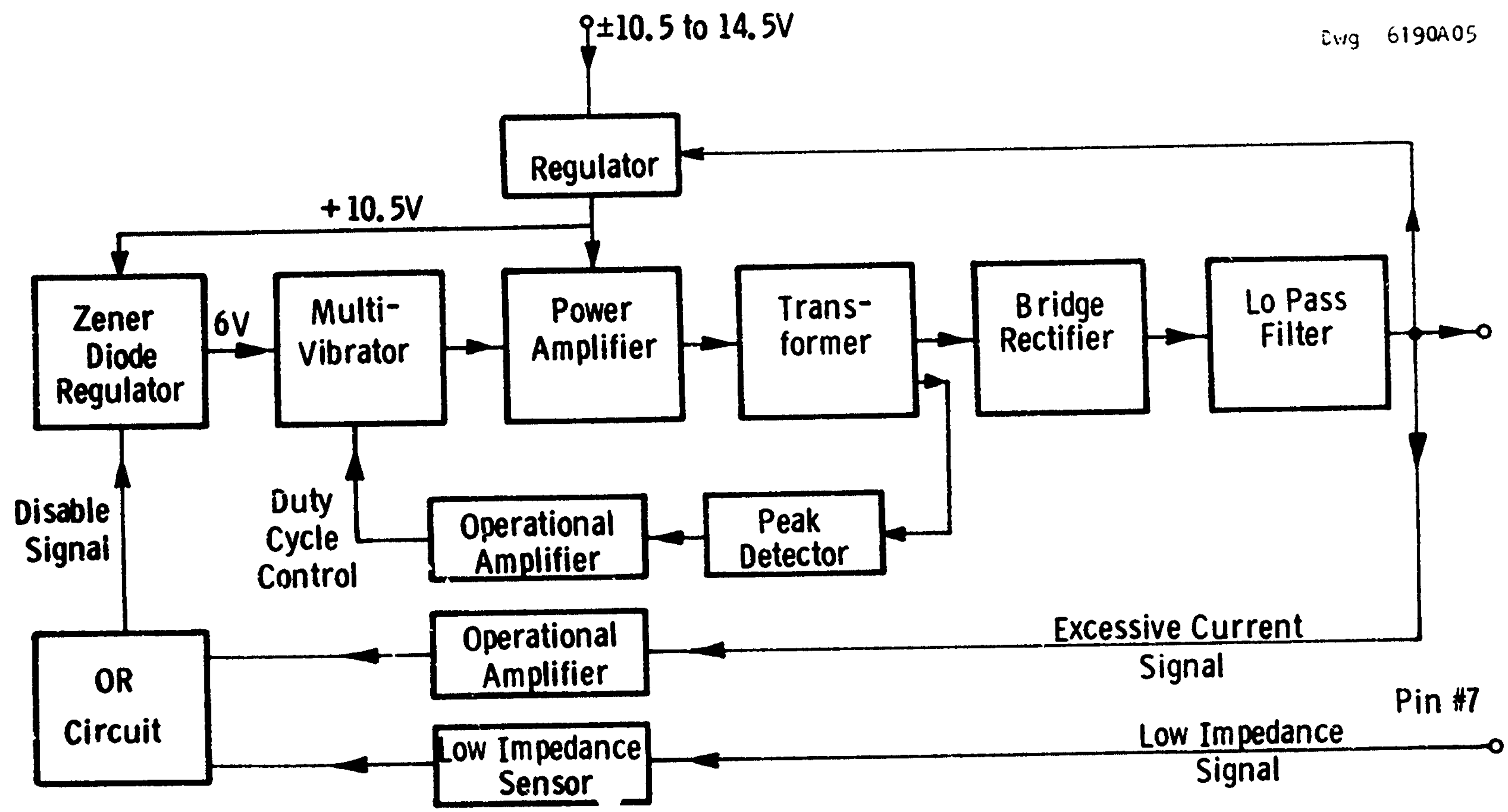
The preamplifier requires 30 volts at 14 milliamperes for proper operation. An additional 15 volts is required to compensate for cable voltage drop and current source simulation. Since the system power supply delivers a nominal ± 12 volts, an up-converter was designed to obtain the required 45 volts. The block diagram for the power converter is shown in Fig. 28.

The basic converter consists of a multivibrator free-running at 20 kHz driving a power amplifier whose square wave output is rectified and filtered. Additional circuits provide the required auxiliary functions described in the following paragraphs.

Because the system power is derived from batteries, the supply voltages drop from a high of approximately 14.5 volts to a low of approximately 10.5 volts as the batteries become discharged. Thus a regulator is required to maintain the amplifier system voltage at 45 volts.

Because of small differences between the positive and negative supply voltages and differing collector saturation voltages of the power amplifier switching transistors, the positive and negative "volt-seconds" applied to the transformer core are unequal. This is equivalent to applying a dc voltage component to the transformer and since the dc resistance is very small, large dc currents can flow which saturate the core. A duty cycle control circuit is included in the converter which senses unequal positive and negative "volt-seconds" in the core and adjusts the multivibrator duty cycle to make them equal.

The converter is protected against excessive output current due to accidental shorts or other high load situations. If excessive current is sensed, a circuit shuts off power to the multivibrator thus removing the power amplifier drive signal and yielding zero output. Once this circuit has been activated, it must be reset by first removing and then reapplying the system power.



Up converter, voitage regulator, and protective cirucits

Fig. 28 - Power Converter and Regulator (Nov. 1972)

In the November 1972 deployment, the input to the low impedance sensor came from the lead connected to the bottom hydrophone. In the future the unused pin #7 on the XSL8CCP connector will be used. When the connector is attached, the resistance from pin #7 to ground is very high. When the connector parts the salt water will reduce the impedance to 500 ohms or less.

The presence of either a low impedance signal or an excessive current signal will cause a signal from the "or circuit" to disable the multivibrator by removing its dc power. A complete schematic of the power supply is shown in Fig. 29.

The voltage regulator schematic is given in Fig. 30. It compares a fraction of the power converter output voltage against an internal reference voltage (across D31). The difference voltage is amplified by OA3 and drives a series pass-transistor, Q31, through a phase-inverting driver stage, Q32. The remainder of the circuit, OA4, Q33, and Q34, make up a unity gain inverting power amplifier to generate a negative voltage equal in magnitude to the positive voltage controlled by the power converter output.

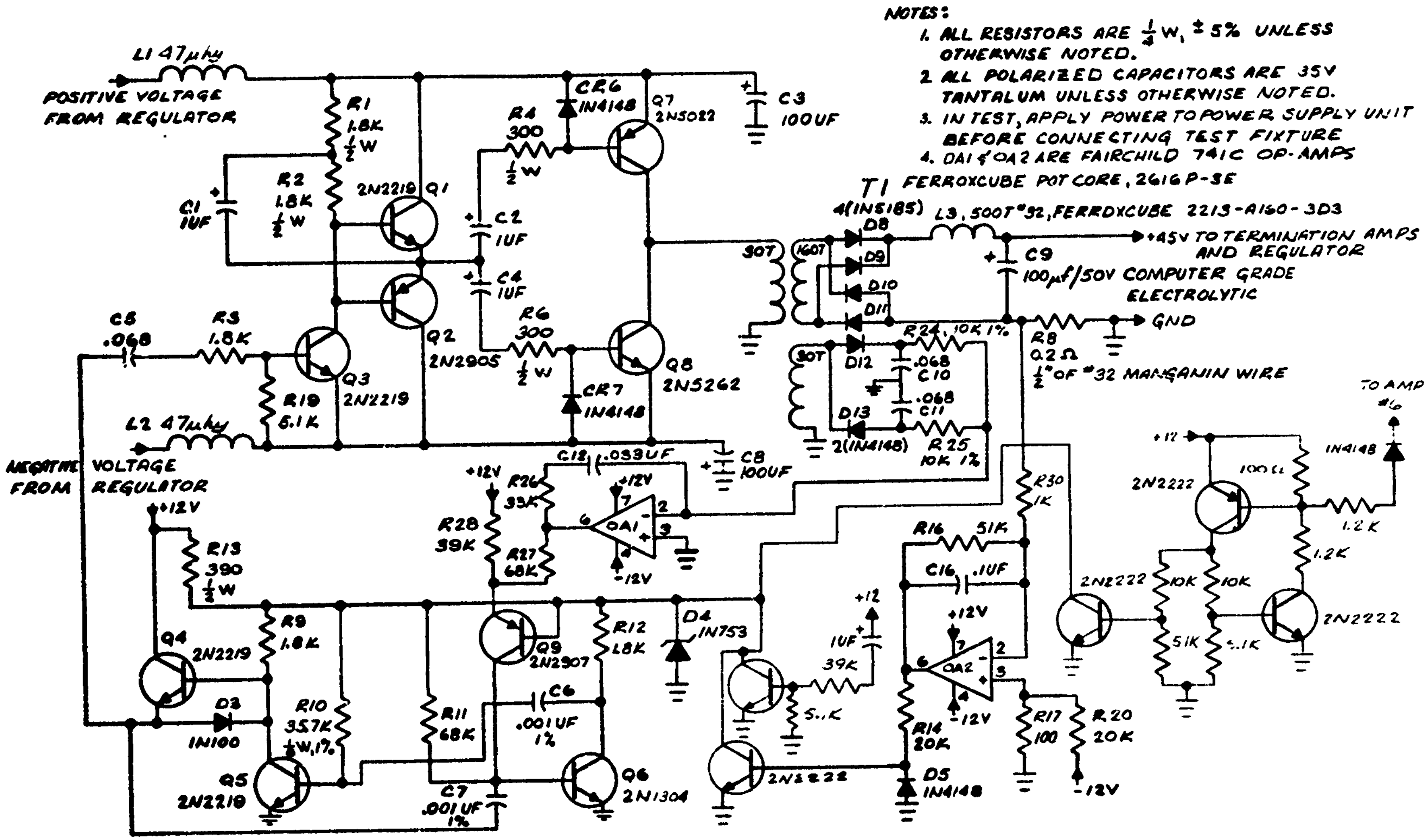


Fig. 29 - Power Converter (Nov. 1972)

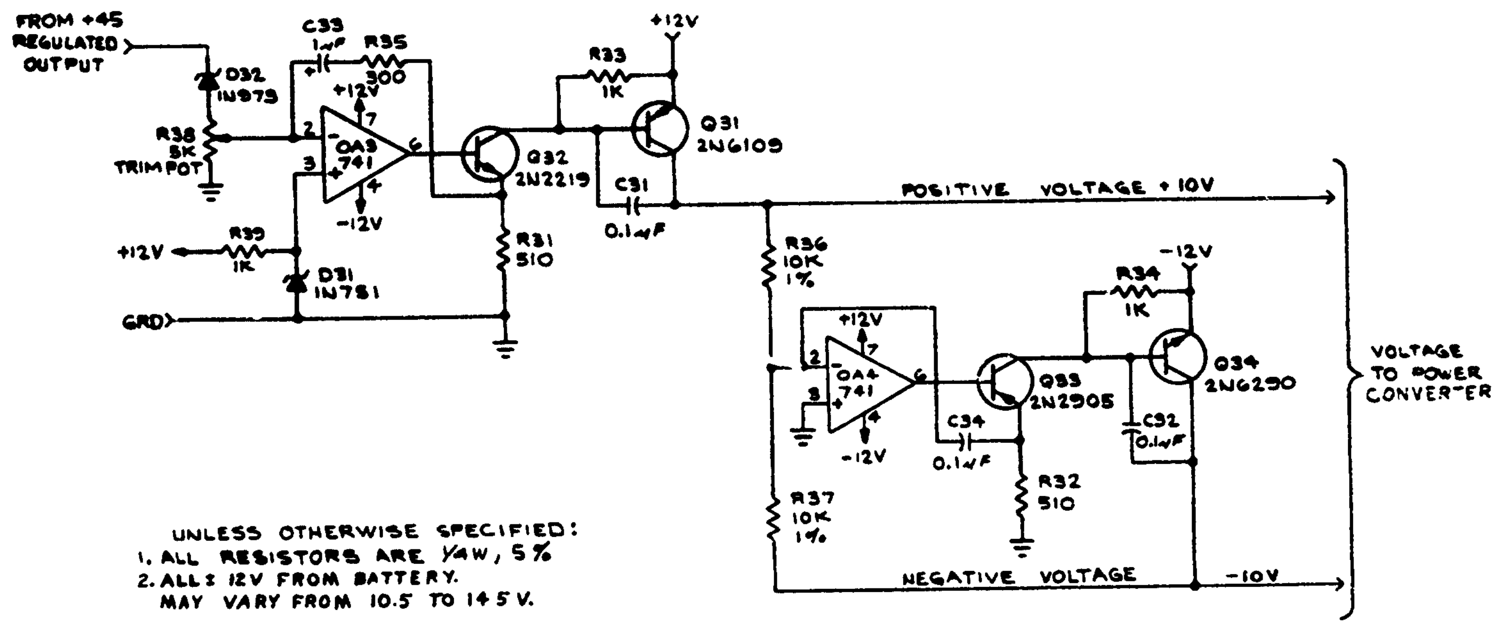
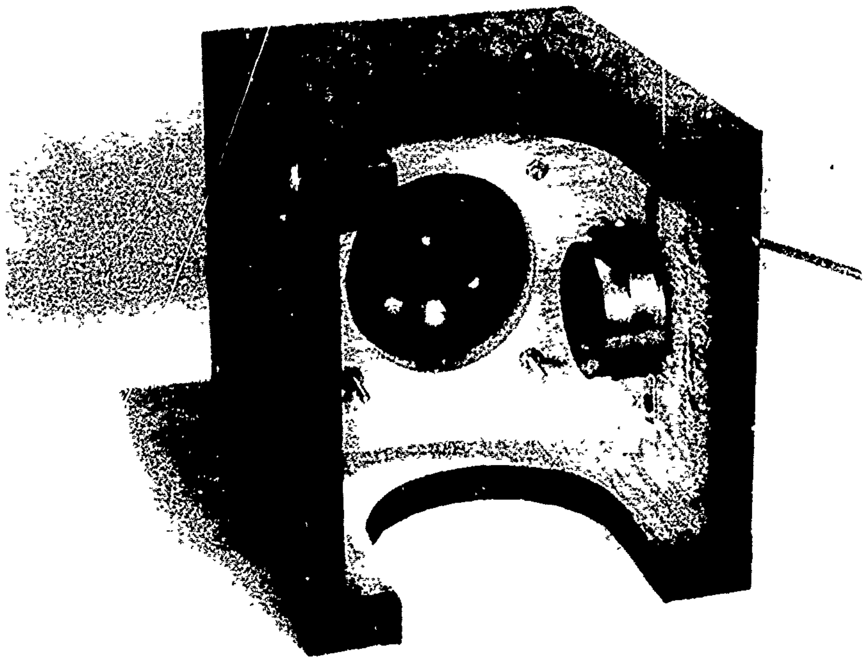


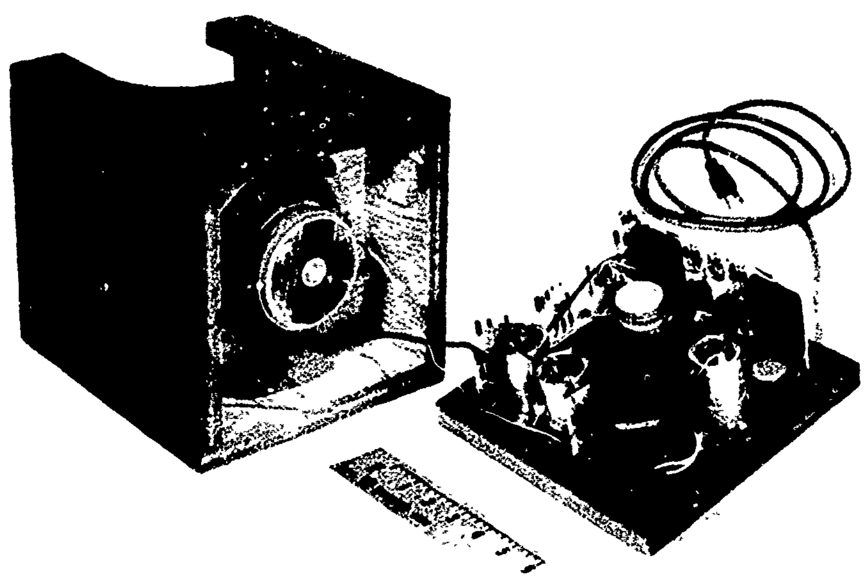
Fig. 30 - Regulator for Power Supply (Nov. 1972)

5. PORTABLE ACOUSTIC TEST UNIT

The acoustic test unit is used for a system check after the hydrophones have been attached to the cables. It consists of a small chamber which has a weatherproof speaker and microphone; see Fig. 31. The back portion of the speaker is loaded into a compliant closed chamber so that the sound pressure from the front produces a monopole pattern. The microphone is a bender disk with a closed back compliant chamber and provides a sensitivity of -139 dBV/μPa from a built-in preamplifier. The frequency of the built-in oscillator covers the range from 50 Hz to 500 Hz. By comparing the output of the ACODAC phone with that of the microphone using a HP 302 narrow band wave analyzer, a hydrophone calibration in air can be obtained.



(a)



(b)

Fig. 31 - Portable Acoustic Calibrator

RM-59804

6. TEST DATA

6.1 Hydrophone Self Noise

The Westinghouse hydrophones were designed to measure shipping noise in the ocean. The Geotec recording system is capable of recording signal levels from 1 mV to 1 V over the frequency range from 10 Hz to 300 Hz by using step attenuators of 10, 20, 30, and 40 dB. Acoustic ambient noise curves, Fig. 32, by Wenz, have two solid heavy lines that give the limits of the prevailing noise in the ocean. Five percent of the time the noise is below the lower curve and five percent of the time it is above the upper curve. A preamplifier that had a noise level at or below the lower Wenz curve from 10 Hz to 300 Hz was considered satisfactory. The calculated noise levels of the preamplifier used was 6 dB below the Wenz curve at 10 Hz and 2 dB below it at 300 Hz; see Fig. 33. This figure also shows the measured response of four of the amplifiers. Response was measured with a H.P. model 302A wave analyzer. An R-C circuit was used to simulate the transducer.

The average noise power represented by the lower Wenz curve from 10 Hz to 300 Hz is the same as the value at 50 Hz. At 50 Hz the curve has a value of

$$+18 \text{ dB re } (2\text{x}10^{-4} \text{ dynes/cm}^2) = -56 \text{ dB re } 1\ \mu\text{B} = +44 \text{ dB re } 1\ \mu\text{Pa}$$

in a 1 Hz bandwidth. Over the 290 Hz band the noise power would increase by a factor of 290 or 25 dB. Consequently, the expected ambient noise level is +69 dB re 1 μPa. The overall sensitivity (hydrophone plus amplifier) of the Westinghouse units were

-129 dBV/ Pa.

(See Table 5 for sensitivities of individual units.) Therefore, a lower Wenz noise level over the band from 10 Hz to 300 Hz would produce a signal level of

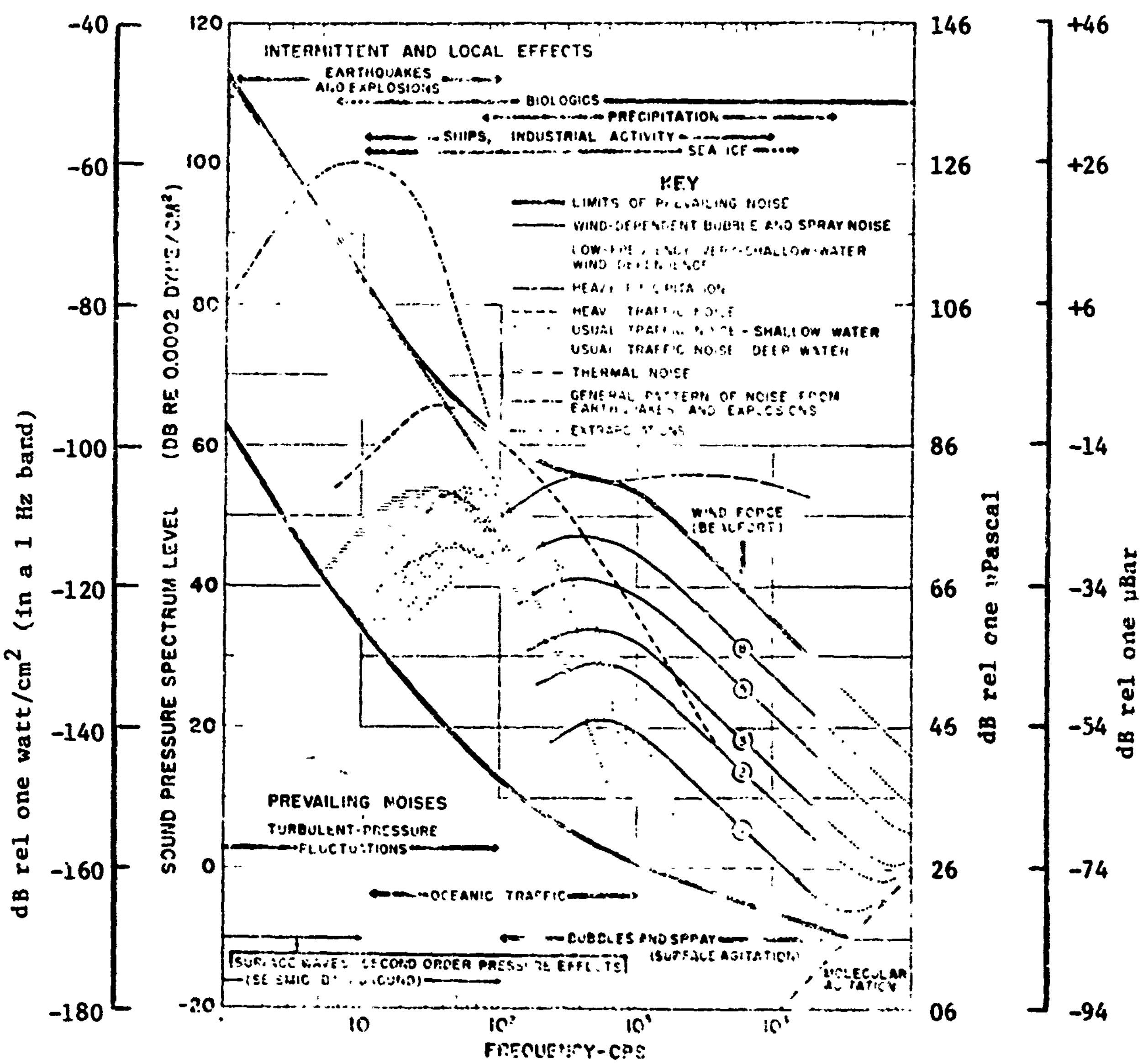


Fig. 32- Acoustic Ambient Noise in the Ocean as Described by G. W. Wenz[3] (some scales added)

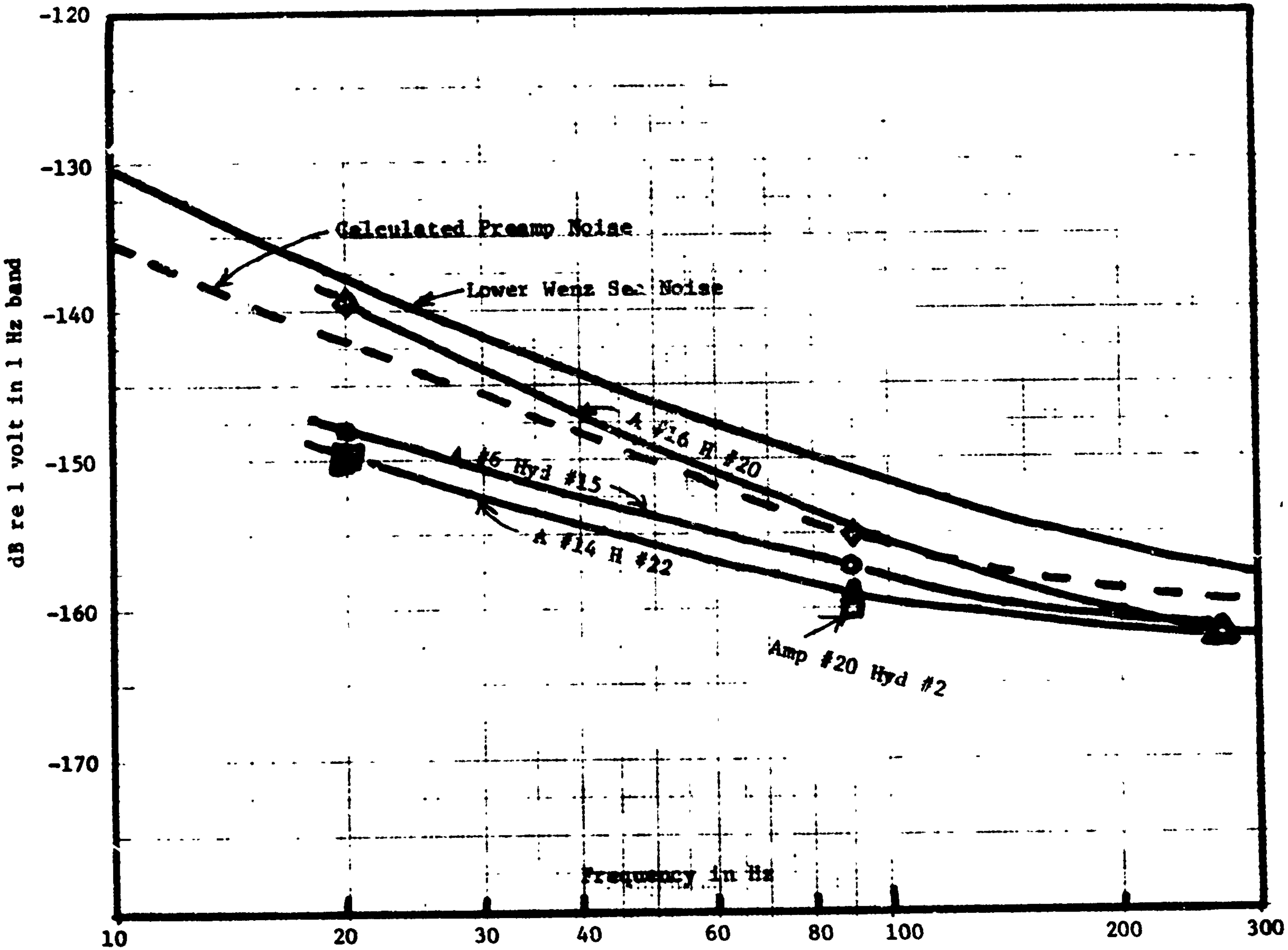


Fig. 33 - Preamplifier Noise

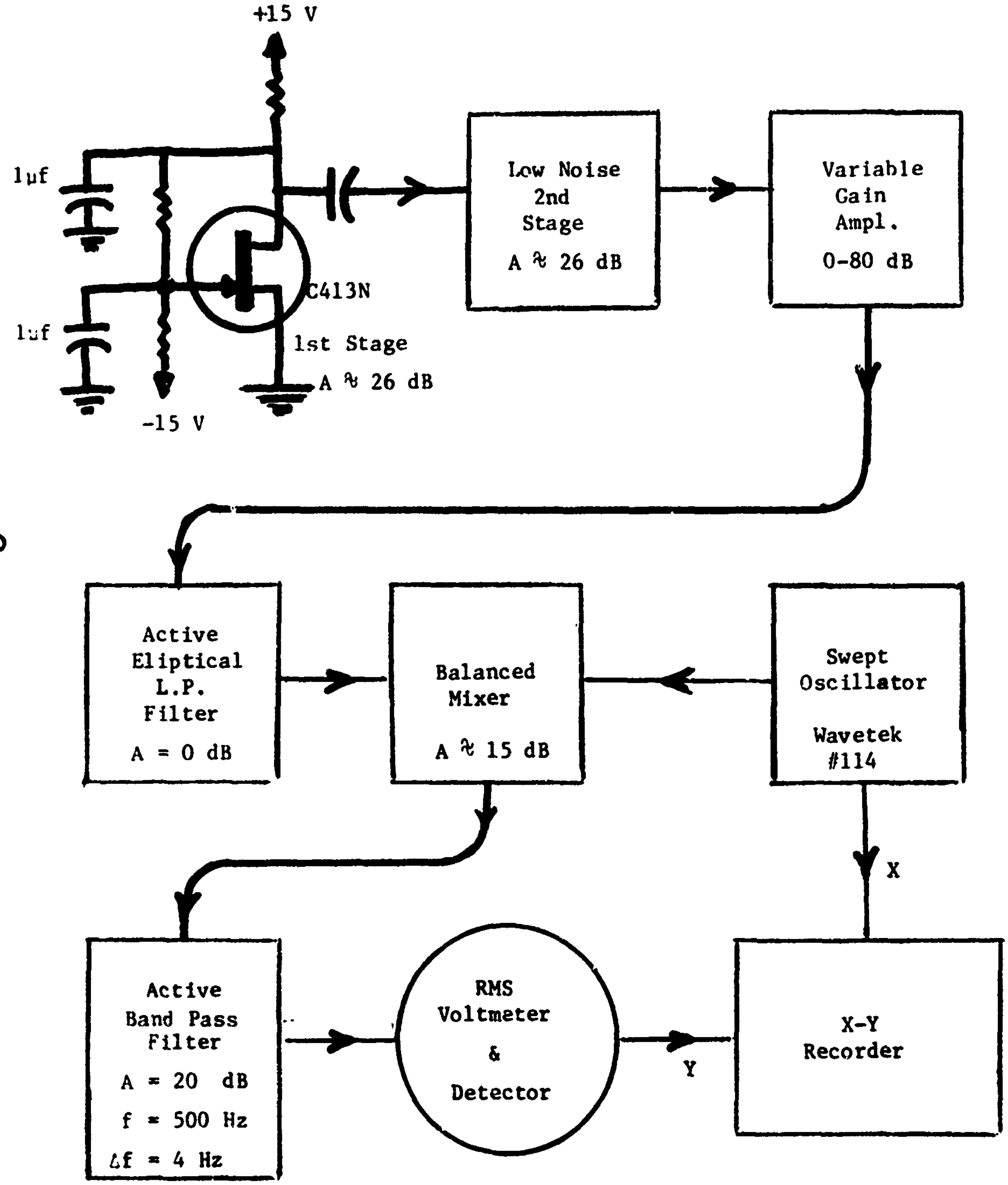


Fig. 34 - Circuit for Noise Measurements of FET Units

$-60\ \text{dB re } 1\ \text{V} = 1\ \text{mV}$

This is also the lowest level that the Geotec recorder will handle.

When the hydrophones are to be used to monitor explosions or other signals that contain an average power more than 60 dB above the lower Wenz curve, saturation will occur.

6.2 Noise Tests of FET Units

In order to determine whether Crystalonics #C413N silicon epitaxial junction N channel low noise FET units could be used in hydrophone preamplifiers, some units were passivated by Ⓦ Solid State Devices Department. The top of the aluminum cans were removed and an organic coating was added. These units were tested in the circuit shown in Fig. 34. A 4 Hz wide filter was used to examine the FET voltage noise over the spectrum from 10 Hz to 300 Hz. Figure 35 is a typical plot of the recorded output voltage. The noise at 60 Hz and harmonics was large due to power line pick up and so was ignored. The units were all temperature cycled up to 150°C for 1 hour, returned to room temperature, heated to 150°C for 2 hours, cooled and tested. Next, the units were placed in a bag of castor oil and were pressure cycled three times to 10,000 psi. Figures 35 and 36 show a noise spectrum before and after the tests. Table 4 summarizes the results at 100 Hz and 250 Hz for the four units. The largest increase was 30% in voltage which was still within the satisfactory range.

Each of the complete preamplifier circuits was tested for noise before assembly to the hydrophone. A dummy RC load was used to simulate the transducer.

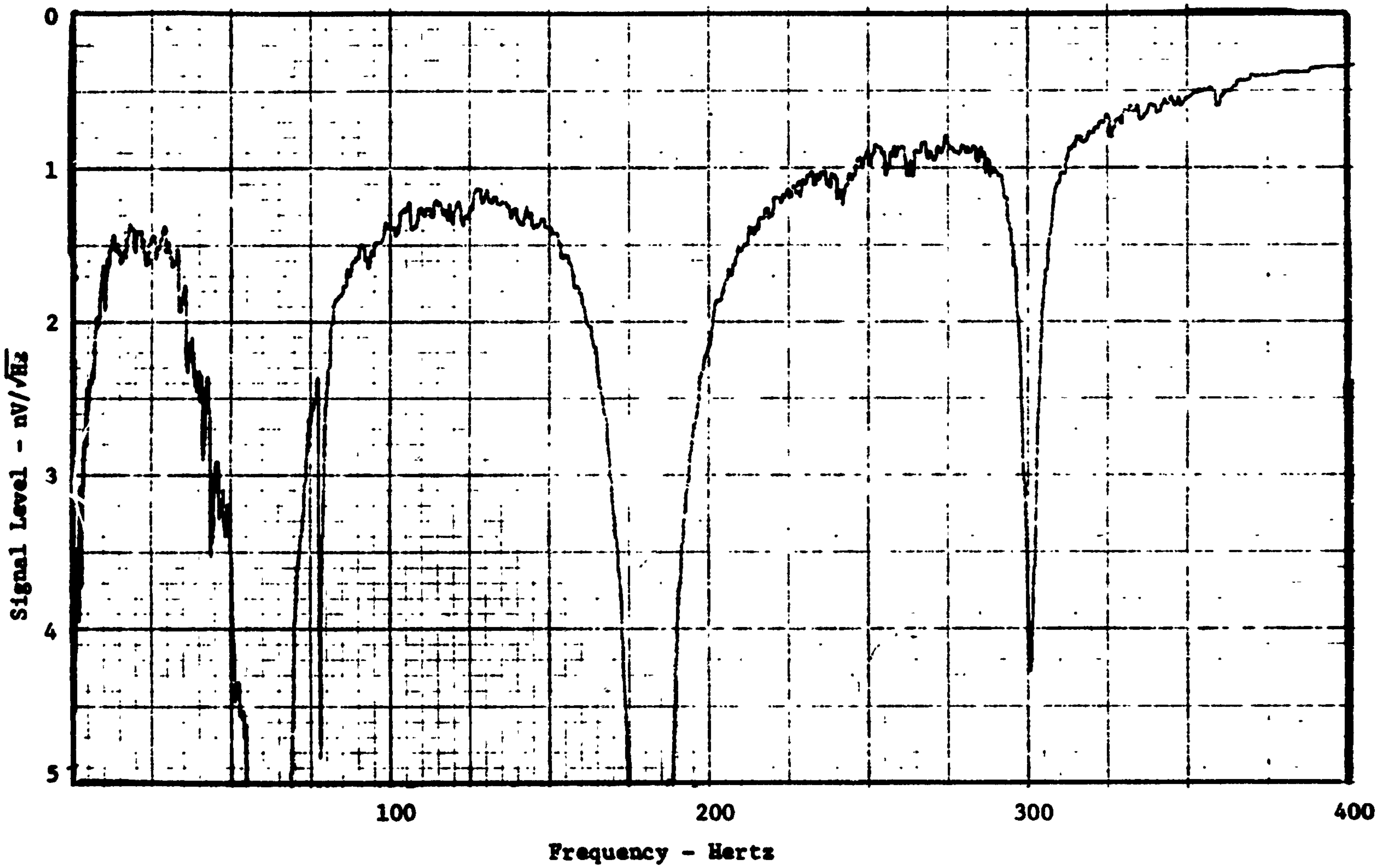


Fig. 35- Noise Level of FET #5 Before Temperature and Pressure Cycling

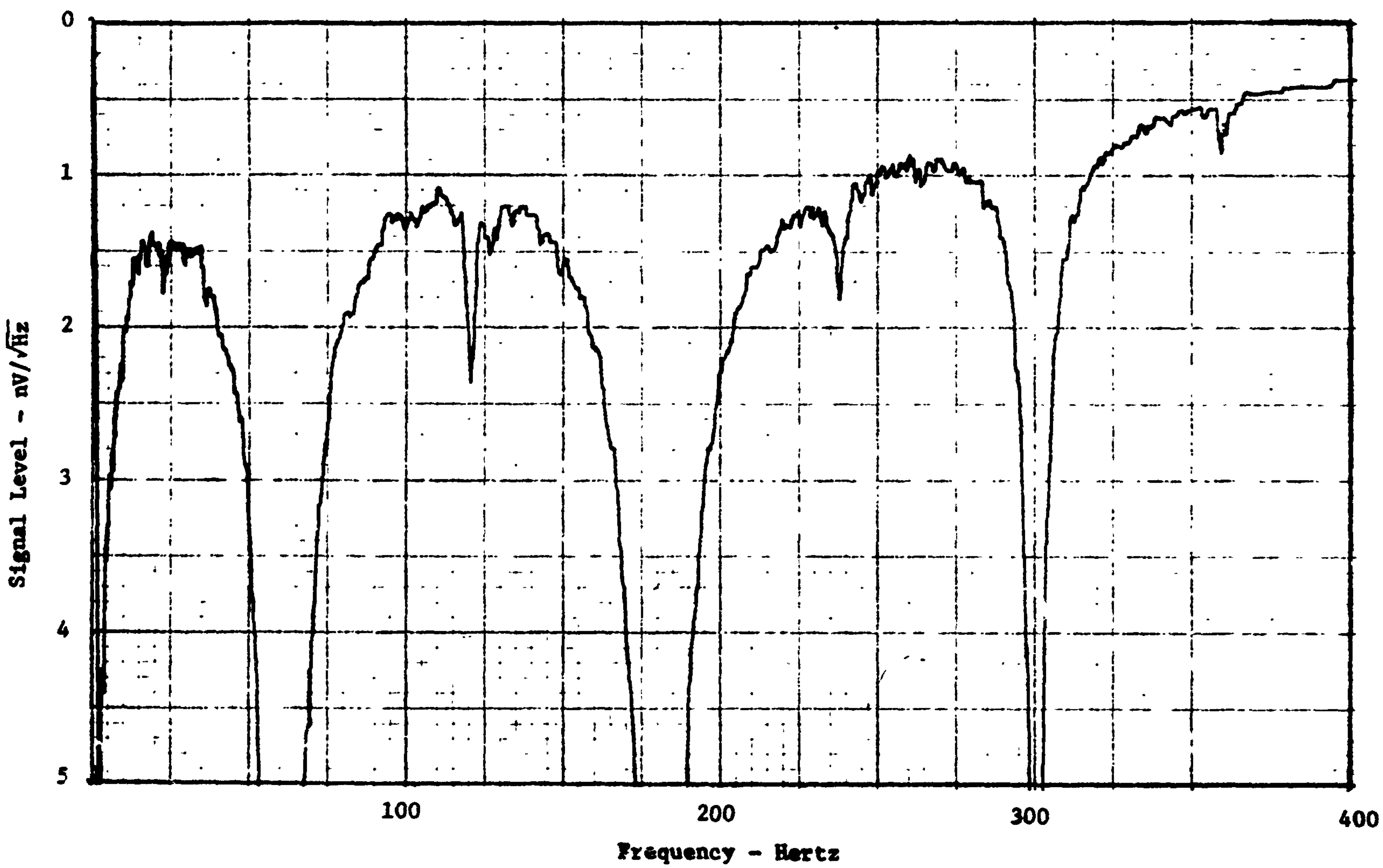


Fig. 36 - Noise Level of FET #5 After Temperature and Pressure Cycling

Table 4 - Noise Test of Crystalonics #C413N

Calculated Input Signal Level in $mV/\sqrt{Hz}$ units

Unit No.	Case Type	Before Passivation		After Passivation		After 2 Temperature Cycles		After 3 Pressure Cycles	
		100 Hz	250 Hz	100 Hz	250Hz	100 Hz	250 Hz	100 Hz	250Hz
2	Short	2.8	2.8	2.8	2.5				
3	Short	1.6	1.5	1.8	1.5	1.8	1.5	1.5	1.3
4	Tall	1.2	0.9	1.3	1.0	1.4	1.0	1.3	1.0
5	Tall	1.0	0.8	1.4	0.9	1.3	1.0	1.3	1.0
6	Tall	1.1	0.9	1.3	0.9	1.3	1.1	1.4	1.0
7	Tall	1.2	0.9	1.5	1.0	1.5	1.1	1.5	1.2

6.3 Hydrophone-Preamplifier Sensitivity

All units were subjected to an 8,000 psi test at 20°C in a pressure bomb filled with oil. After the pressure test the units were calibrated in air using a 15" speaker driven by an audio oscillator. The strength of the sound field was monitored using a B&K quarter inch condenser microphone Type 4135 with cathode follower Type 2615, having a sensitivity of -71.4 dBV/μBar. The air measured sensitivity before and after deployment is given in Table 5. The response of any one hydrophone was constant within ± 1 dB from 10 Hz to 300 Hz. The test setup is shown in Fig. 37. Before the next deployment, units will be calibrated as a function of frequency, static pressure, and temperature at USRD of NRL.

6.4 Acceleration Sensitivity

During the hydrophone assembly, but prior to oil filling, vibration tests were made to determine the sensitivity of the hydrophone to acceleration. Units were mounted so they could be vibrated axially in air using a Goodmans Industries Ltd. Type 390A force driver. The motion was monitored with a Consolidated Electrodynamic Corp. Type 4-275 calibrated accelerometer with a sensitivity of -48.6 dBV/g mounted on the hydrophone case. The test was made at 100 Hz and the results are shown in the last column in Table 5. These tests indicated that the acceleration response per milli-g was -58 dBV or less.

6.5 Amplifier Tests

The gain of all preamplifier units was measured by inserting a 10 μV signal at the input terminals and measuring the output voltage from the termination amplifier. A gain between 59 dB and 60 dB was considered satisfactory. Amplifier noise tests were made at 20, 90, 270, and 1000 Hz using a 1000 ohm resistor in series with a 4700 pf condenser connected to the input terminals, as a dummy source, in place of the hydrophone. After the amplifier units were potted and assembled to the hydrophone, noise tests were made in an anechoic chamber at 270 Hz and 1000 Hz. At frequencies below 270 Hz, the chamber noise masked the preamplifier noise. The gain of a number of potted amplifier units was monitored in the pressure bomb as the pressure was slowly varied from

Table 5 - Calibration Data for W String Used on November 1972 Deployment

Hydrophone Location	W Hydrophone Number	Pressure Sensitivity		Acceleration Sensitivity
		Before Deployment	After Deployment	Before Deployment
		dBV/μB	dBV/μB	dBV/μg
#1 Top	2	-29	-27	-74
#2	24	-32	-32	-59
#3	15	-28	-29	-77
#4*	20	-28	-38	-63
#5	22	-27	-28	-59
#6 Bottom	27	-27	-28	-58

*This unit was taken apart after deployment. Part of the silver coating on the ceramic cylinder had reacted with sulphur present in the silicone oil. A new design eliminates this problem.

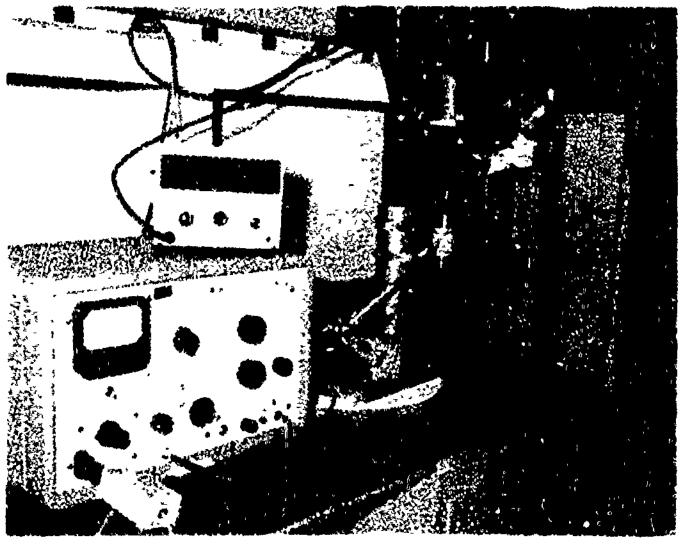


Fig. 37 - Test Set Up for Vibration Measurements

0 to 10,000 psi and back down again. No significant change in gain occurred. The amplifier has 40 dB of negative feedback so it has a stable gain even though the characteristics of some of the components may change with pressure.

8. CONCLUSIONS

The November 1972 deployments demonstrated that a long array of WX-VERAY-1 hydrophones is easy to deplov and recover. The one month 630 mile trip in the ocean proved that the units are rugged.

Improvements should be made in the termination amplifier assemblies so that they can be more readily replaced or repaired. Some circuit refinements in the power converter unit are also recommended. Since the power supply voltage varies from ± 14.5 to ± 10.5 volts as the batteries discharge, circuit performance will be measured over this range of voltages.

In the future, hydrophones will be calibrated at 4°C at pressures from 0.7 to 56 MPa over the frequency range from 3 Hz to 300 Hz at the Naval Research Laboratory in Orlando, Florida before they are deployed.

9. PERSONNEL

The following people were involved in the work and as authors of various portions of this report: C. Hikes of Westinghouse Oceanic Division, Bay Bridge, Maryland; C. H. Jones, G. R. Douglas, A. Nelkin, C. F. Petronio, and J. H. Thompson of Westinghouse Research Laboratories, Pittsburgh, Pa.

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2. C. B. Durgin, "All Transistor Hydrophone Preamplifier," JASA V. 34 p. 1998(A) 1962, or Westinghouse Scientific Paper 62-814-437-P1.

3. G. W. Wenz, "Acoustic Ambient Noise in the Ocean: Spectra and Sources," JASA V. 34, p. 1952 (Fig. 13) 1962.

4. Texas Instruments, Inc., "Casualty Report for Recovered ACODAC Array December 1972," prepared for ONR January 1973.

5. C. L. Hikes, "ACODAC Array: Cable, Terminations, and Connectors," OR&EC Report No. OER 73-19, July, 1973.

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Report Number	Personal Author	Title	Publication Source (Originator)	Pub. Date	Current Availability	Class.
Unavailable	Brancart, C. P.	TRANSMISSION REPORT, VIBROSEIS CW ACOUSTIC SOURCE, CHURCH ANCHOR EXERCISE, AUGUST AND SEPTEMBER 1973	B-K Dynamics, Inc.	730101	AD0528904	U
Unavailable	Daubin, S. C., et al.	LONG RANGE ACOUSTIC PROPAGATION PROJECT. BLAKE TEST SYNOPSIS REPORT	University of Miami, Rosenstiel School of Marine and Atmospheric Science	730101	AD0768995	U
NUSC TR NO. 4457	King, P. C., et al.	MOORED ACOUSTIC BUOY SYSTEM (MABS): SPECIFICATIONS AND DEPLOYMENTS	Naval Underwater Systems Center	730105	AD0756181; ND	U
MC-012	Unavailable	CHURCH GABBRO SYNOPSIS REPORT (U)	Maury Center for Ocean Science	730210	ND	U
Unavailable	Hecht, R. J., et al.	STATISTICAL ANALYSIS OF OCEAN NOISE	Underwater Systems, Inc.	730220	AD0526024	U
Raff rept 73-2	Bowen, J. I., et al.	EASTLANT SHIPPING DENSITIES	Raff Associates, Inc.	730227	ND	U
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Unavailable	Daubin, S. C.	CHURCH GABBRO TECHNICAL NOTE: SYSTEMS DESCRIPTION AND PERFORMANCE	University of Miami, Rosenstiel School of Marine and Atmospheric Science	730601	AD0763460	U
MC-011	Unavailable	CHURCH ANCHOR EXERCISE PLAN (U)	Maury Center for Ocean Science	730601	ND	U
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64	Jones, C. H.	LRAPP VERTICAL ARRAY- PHASE II	Westinghouse Research Laboratories	730613	AD0786239; ND	U
Unavailable	Koenigs, P. D., et al.	ANALYSIS OF PROPAGATION LOSS AND SIGNAL-TO-NOISE RATIOS FROM IOMEDEX	Naval Underwater Systems Center	730615	AD0526552	U
NUSC TR 4417	Perrone, A. J.	INFRASONIC AND LOW-FREQUENCY AMBIENT-NOISE MEASUREMENTS OFF NEWFOUNDLAND	Naval Underwater Systems Center	730619	ND AD913668	U
USRD Cal. Report No. 3576	Unavailable	CALIBRATION OF FLIP-CHURCH ANCHOR TRANSDUCERS SERIALS 15 AND 19	Naval Research Laboratory	730716	ND	U

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